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Application of Context Aware Systems to Support Knowledge Work in the Aerospace

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List of Abbreviations and Acronyms

AKM	Airbus Knowledge Management
CS	Customer Service
DAML	DARPA Agent Markup Language
DCMI	Dublin Core Metadata Initiative
FBCC	Feedback Based Context Capturing
FS KM	Fuel System Knowledge Management
HTML	Hyper Text Markup Language
irON	instance record and Object Notation
ISQ	In-Service Query
ISS	In-Service Support
KPI	Key Performance Indicator
MS	Microsoft
OWL	Web Ontology Language
RDF	Resource Description Framework
SA	Single Aisle
SPARQL	Simple Protocol and RDF Query Language
SQL	Structured Query Language
VBA	Visual Basic for Application
WB & LR	Wide Body and Long Range
WYSIWYG	What You See Is What You Get
XML	Extensible Markup Language

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Abstract

This thesis describes research of an Engineering Doctorate research project jointly facilitated by Airbus and University of Bath. The overall research aim was to *investigate the application of context aware systems to capture and utilise context to support knowledge work in the aerospace industry*. Context aware systems provide the potential capabilities to capture and utilise context to distribute information relevant to users' needs. These capabilities are perceived to be ideal to support knowledge work, however there is still much to be learnt about how context aware systems can be developed and applied in daily engineering activity.

Resulted from the literature review, the classifications of context and context aware techniques reflect how context were defined and dealt within existing literature. Applications provided by existing context aware systems to support knowledge work were summarised. Additionally, research issues of industrial applications for context aware systems were discussed. The research gaps, resulted from the state of the art review, identified potential areas for research and development. After industrial case studies, the context requirements for an ideal context aware system to support knowledge work were identified. Key findings from these research activities were then synthesised to clarify research directions in the latter part of the research.

In the latter part of this research, an experiment was designed and executed to capture and utilise domain context in the Wing In-Service Support department. Using the repair case search activity as the engineering use case, the context aware system Daedalus was developed to enable **F**eedback **B**ased **C**ontext **C**apturing (FBCC), and then utilised the captured context to facilitate *search terms expansion* and *search terms suggestion* to support repair case search. The experiment data generated from this experiment enabled the following studies: a detailed examination of the domain semantic context of Wing In-Service Support; evaluation of the cost-effectiveness of the FBCC approach; and evaluation of *Daedalus* in terms of adoption level and impact on repair case search activity.

From the study results of the experiment data, a number of contributions of this research were confirmed. The in-depth examination of domain semantic context revealed key insight for future research and development of context aware systems. The *FBCC* approach can be regarded as a novel approach to facilitate user-driven context capturing in a cost-effective manner. The *Daedalus* system was proven to have provided significant efficiency gain to the Wing In-Service Support department.

Since this research, the usage of Daedalus has been maintained with the existing user base and also expanded to new In-Service teams. These post-experiment usage, maintenance and development of Daedalus can be considered as evidence of continuous industrial impact of this research on the collaborating engineering department as well as wider engineering communities within Airbus.

1 Introduction

The rise of information technology has ushered in an explosion of digital information (Korth & Silberschatz, 1997; Sweeney, 2001). Information is generated with ever increasing ease and captured in various digital data repositories while information users face increasing difficulties to identify and retrieve useful information. In the corporate domain, technologies such as social computing have opened up new ways for knowledge workers to organize information and exchange knowledge (McAfee, 2009). However, advances in technology also generate challenges and problems for corporations to adapt their information organisational practices to the new technological landscapes in order to achieve or maintain competitive advantages.

For the aerospace industry, an added challenge for organizing information is that extended product lifecycles require such information to be organized and accessible throughout long periods of time. For example, the repair and operational history of a given aircraft typically spans 2-3 decades. Within such a long lifecycle, multiple generations of information systems may have been used and become obsolete, and access to information needs to encompass and cope with such diversity. Moreover, industrial protocol, engineering language, and business practice are changing all the time, yet future generations of aerospace engineers and designers still need access and *to make sense* of today's information.

This thesis provides detailed information about the Engineering Doctorate research the author undertook from 2007 to 2013 focusing on the challenges summarised above. This is an Engineering Doctorate research project jointly facilitated by Airbus and University of Bath. In this introductory chapter, the overall industrial context in relation to the aerospace industry is presented in 1.1. The research background and motives are presented in 1.2. Key concepts that underpin much of the research projects such as data, information and knowledge are discussed in 1.3. In 1.4, an overall introduction is presented on the subject of investigation of this thesis – Context and Context Aware Systems. The research aims and objectives are then outlined in 1.5, followed by discussion on the methodology in 1.6. Finally, the overall layout of this thesis is presented in 1.7

1.1 Overall Industrial Context

In this section, the overall industrial context of this research project is outlined. An introduction to the sponsoring company Airbus is presented in 1.1. This is followed by a discussion in 1.2 on the nature of aerospace knowledge.

1.1.1 Airbus – A Leading Aircraft Manufacturer

Originally under the name Airbus Industrie, Airbus was formed in 1967 as a consortium of British, French and German aerospace manufacturers with an aim to challenge American domination of the aerospace industry. This consortium was integrated in 2000 to form a single entity under the name of Airbus S.A.S. (Airbus S.A.S., 2013a).

Airbus delivered its first aircraft − an A300B2 − in 1974, and has since become a leading aircraft manufacturer, consistently capturing approximately half of the commercial aviation market place (Airbus S.A.S., 2013b). As of July 2013, Airbus produces the following commercial aircraft models with total deliveries of 7977 and 7360 aircraft in operation, as seen in Table 1-1:

- **A300 and A310**: The early twin aisle models, production for both models ceased in 2007.
- **The Single Aisle (A320) family**: Single aisle family including A318, A319, A320 and A321. These are by far the most sold models among airbus aircraft with a total delivery of more than 5600.
- **A330, A340 and A350**: The long range twin aisle models. A350 will be the first Airbus aircraft with both fuselage and wing structures made primarily of composite materials. This model is scheduled for first delivery in mid-2014.
- **A380**: Double-deck, twin aisle and long range model, the world biggest commercial airliner. This is the newest model and has been in service since 2007.

	A300/A310	Single Aisle	A330/A340/A350	A380	Total
Total Orders	816	9812	2314	262	13204
Total Deliveries	816	5677	1378	106	7977
Aircraft in Operation	425	5418	1348	106	7360

Table 1-1: Airbus Total Orders, Deliveries and Aircraft in Operation as of July 2013 (Airbus S.A.S, 2013c)

The typical development of a new aircraft model, from the early feasibility studies to entry-into-service, requires between 10-15 years. The average in-service life span of an aircraft is about 40 years. Such long design and product lifecycles, as well as the safety-critical nature of aircraft design, are the defining features of the aerospace industry.

From a technology perspective, different generations of technologies from different disciplines – mechanical, material, electrical and computational to name a few – have to be compatible with each other and co-exist in a highly constrained environment. As the aerospace industry becomes more and more mature, the knowledge required for engineers to be productive are becoming increasingly complex, as described below.

1.1.2 The Nature of Aerospace Knowledge

Aerospace engineers are what Peter Drucker described as knowledge workers − "who works primarily with information or one who develops and use knowledge in the workplace" (Drucker, 1959). The engineering activities performed by these engineers are regarded as knowledge work which is characterised by features such as “*abstractly defined task, flexible application of knowledge, worker’ autonomy, continuous innovation and learning into job roles*” (Brinkley, Fauth, Mahdon, & Theodoropoulou, 2009).

With advancing technologies and ever more globalised companies, it has been observed that the knowledge required for an individual to be productive and for the organisation to be competitive is becoming more and more complex. Moreover, it needs a long learning curve for the acquisition of such knowledge (Delong, 2004). This is particularly the case for large organisations in mature industries such as aerospace where knowledge workers often have to navigate different knowledge disciplines (Garrick & Clegg, 2000), use both state of the art and legacy technologies and collaborate with colleagues from multi-cultural backgrounds (EADS, 2011).

Given the complexity of knowledge and the difficulty of its acquisition, it is not surprising that the productivity of knowledge workers is often closely related to their experience on the job (Strack, Baier, & Fahlander, 2008). Studies have shown that for senior employees, their critical knowledge often comes in the forms of pattern recognition, social norms and relationships, which need to be accumulated in time and are difficult to learn due to their tacit nature (Casher & Lesser, 2003). As knowledge becomes more complex, it is also more difficult to transfer and replicate (Delong, 2004).

Meanwhile, the aerospace industry increasingly faces knowledge loss due to demographic changes in the working population. It has been acknowledged that the global working population are ageing and shrinking at the same time (Kannan & Madden-Hallett, 2006; Stam, 2009).As employees get older and retire, business faces significant losses of critical knowledge, skills and productivity (Strack, Baier, & Fahlander, 2008). Tom Enders, CEO of Airbus from 2007 to 2012, highlighted that the aerospace industry is at risk of "*losing the experience and intellectual capital it has taken half a century to build*" (EADS, 2011).

In the face of this risk of knowledge loss, it is of paramount importance to investigate how know-how and skill of experienced engineers can be captured in a manner that it can be efficiently transferred to younger generations of engineers (Ahmed, Wallace, & Blessing, 2003). With this overall industrial context, the research background is grounded in inter-related fields such as knowledge management and information technology. This is discussed in 1.2.

1.2 Research Background and Drivers

The research background of and motivations for this research project are introduced in this section. Firstly related research fields that form the research background are introduced in 1.2.1. Secondly, the motivation of this project are discussed in 1.2.2

As discussed in 1.1, a major risk faced by the aerospace industry is that of knowledge loss due to working force demographic change in the 21st century. This provided the impetus for much research work in knowledge management and information technology. In particular, research in the subject of context aware systems is closely related to this project.

1.2.1 Knowledge Management

In order to prevent or remedy loss of knowledge, organisations such as Airbus actively promote knowledge management practices as well as engaging in research activities (Barnard & Rothe, 2003). As a subject, knowledge management is concerned with how individuals and organisations manage their intellectual capital and knowledge (Sveiby, 2001). From an organisation perspective, knowledge management is regarded as a critical element of organisational learning (Wang & Ahmed, 2003).

The majority of organizations believed that much of the knowledge they needed existed inside the organization, but to identify it, find it, and leverage it remained problematic (Cranfield University, 1998).For this reason, much research work in this field focused on how organisations can facilitate the sharing and learning of experience and insight among its knowledge workers to create value (Ackerman, Pipek, & Wulf, 2003; Weber, et al., 2007). It has been observed by multiple studies that a key element that facilitates such sharing and learning of knowledge is information technology (Earl, 2001; Alavi & Leidner, 2001).

1.2.2 Information Technology

Knowledge management and information technology are often considered to be inter-related. Many knowledge management approaches were originated in IT/IS areas (Damsgaard & Scheepers, 2001; Goodwin, 2009). Alavi and Leidner (2001) pointed out that despite the variety of knowledge management approaches, information technology or information systems have a central role to play in most knowledge management activities in the 21st century.

Moreover, Information technology is often identified either as a key component or key enabler of knowledge management (Earl, 2001) , allowing knowledge to be captured, codified, and reuse efficiently. It has been observed that most of the research on knowledge management conducted in the engineering field is aligned with approaches that propose new software tools to support the management of information (Vianello, 2011).

In addition to being a key enabler for knowledge management, information technology has also changed the way in which engineering work is conducted. After rapid advance in this field since the early 90s, terms such as “file” and “document” now relate more with digital entities in the cyber space than piles of paper, while verbs such as "search" entail a digital command as much as a physical action.

Among many technology advances in this field, the following are particularly recognised to have impact on knowledge management practices: First of all the rise of information search engines has changed how people search for information (Introna & Nissenbaum, 2000) ; secondly phenomenon such as social networking has changed how information can be created, accessed and exchanged (Kaplan & Haenlein, 2010). Another up-and-coming topic that is of particular interest is that of context aware systems (Clark, 2010). It is within this topic that this research project is grounded.

More technical details of this subject are introduced in 1.4.2, and then reviewed in Chapter 2. From a functional point of view, Context aware systems provide the potential capabilities to capture and utilize contextual information that are relevant to users' information need, and allow valuable information to be distributed to the right user at the right time (Dey, 2001).

Many potential venues of usage for context-aware systems have been proposed including smart office, location guidance, e-commerce and information retrieval (Hong, Suh, & Kim, 2009). As for this research project, the potential application of what can be thought of as context aware systems applications to support knowledge work is of particular interest. This idea is now discussed and developed.

1.2.3 Motivations

Since the turn of the century, various research projects within the aerospace industry have taken place to explore the application of context aware systems. With proposed application such as information push (Campbell A. , 2006), information search (Redon, Larsson, Leblond, & Longueville, 2007) and semantic annotation (Malin, Millward, Gomez, & Throop, 2010), these projects aimed to capture and utilise the context under which engineers are working, so that salient information can be identified and delivered.

From a knowledge management perspective, the potential capabilities of context aware systems to capture and utilise context are much desired, since context is a key element to knowledge retrieval, knowledge transfer and knowledge interpretation. Alavi and Leidner stated that the amount of contextual information is the most at issues for knowledge of individuals or groups to be understood by another (Alavi & Leidner, 2001). Ideally, such engineering context shall be captured in seamless manner as part of daily engineering process, and utilised to support engineers in both daily operational activities as well as long term knowledge acquisition.

However, there is still much to be learnt about how context aware system can be developed and applied in daily engineering activity. For instance, there is a lack of studies on how specific nature of engineering context might influence the development of context aware systems. There are also few demonstrations of actual benefit by the application of such systems. Thus the basic motivation of this research project was to *investigate how context aware systems can be successfully applied to support knowledge work in the aerospace industry*.

1.3 Data, Information and Knowledge

Throughout this research project, data, information and knowledge are fundamental concepts that underpin the research activities. For the purpose of this thesis, it is worthwhile to address these concepts early on and clarify the position the author takes with regards to these concepts. In the following, a brief review on various interpretations regarding these concepts is presented in 1.3.1, while the interpretation that is adopted by this research is outlined in 1.3.2

1.3.1 A Brief Review on various interpretations

Among these three concepts, the definition of data is relatively clear, that data are elements that combine and form information (Abram , 1997; Chun, Detlor, & Turnbull, 2000; Davenport & Prusak, 1997). For example "*known facts or specific details held within the global form of information*" (Court, 1995). However, the delimitation of, and relationships between, information and knowledge is often a subject without consent. For example, their application is sometime exchangeable. Knowledge can be *"specific information about a subject",* while information can be defined as *"knowledge acquired through experience or study"* (Collins English Dictionary, 2005).

From a knowledge management perspective, one of often asked questions is "whether knowledge can exist independently from the mind". On one hand, the influential authors Nonoka and Takeuchi (1995) who proposed that knowledge can be captured in the form of "explicit knowledge" as oppose to "tacit knowledge" in the mind. On the other hand, there is the school of "internal view" that "knowledge is a justified personal belief" (Davenport & Prusak, 1997; Alavi & Leidner, 2001; Zins, 2007), and that "explicit knowledge" is just information.

Zins (2007) addressed these different definitions by interpreting the relationships between data, information and knowledge in an integrated manner. Firstly, he presented 130 definitions of data, information and knowledge from 45 scholars. He then examined each definition on whether data, information and knowledge can exist on either or both of subjective domain (SD) or universal domain (UD), where SD is the domain where inner phenomena bound in the mind and UD is where phenomena external to the mind occurs. As a result, a group of 5 models are presented, each representing a distinct view on data, information and knowledge with regard to SD and UD, as seen in the following Table 1-2

Model 1		**Model 2**		**Model 3**		**Model 4**		**Model 6**	
UD	**SD**	**UD**	**SD**	**UD**	**SD**	**UD**	**SD**	**UD**	**SD**
D		D		D		D	D	D	D
I			I	I	I	I	I	I	I
	K		K	K	K		K	K	K

Table 1-2 Different interpretation of Data, Information and Knowledge

This grouping method provides a useful reference on understanding different views on data, information and knowledge with regards to the human mind and the physical worlds. However, this work did not take into account the different forms in which information might exist in the physical world. For this, a framework provided by Floridi (Floridi, 2010, p. 20) offered a holistic view. He proposed an "informational map" which maps the data-information-knowledge continuum with different forms, structure and functions that information might appear to be in, this is shown in Figure 1-1 below.

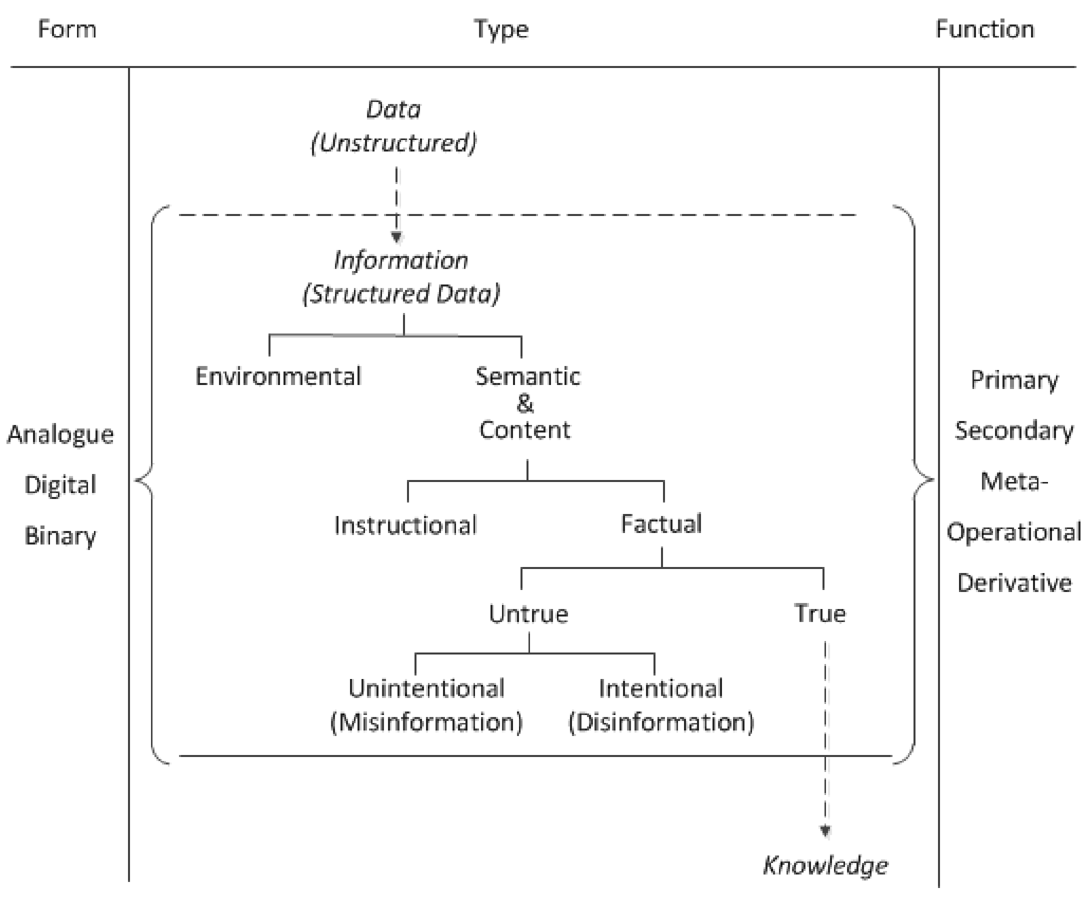


Figure 1-1 A map of information concepts (Floridi, 2010)

Within this "informational map", the concept of information is an umbrella term that consists of data which take different forms (analogue, digital and binary), serve different functions (primary, secondary, meta, operational and derivative), and can manifest into different types. For example, information from an electronic document contains digital data structured according to certain semantic and content standards. While in more complex forms, information can be knowledge existing as internal phenomena to the human mind consisting of analogue (i.e. biological) data.

In particular, Floridi (2010) specified the five functional types of data which information can consist of, as seen in the following table:

Functional Type	Descriptions	Examples
Primary data	The principle data stored in a database.	A simple array of numbers in a spread sheet, or string of zeros and ones
Secondary data	The converse of primary data, constituted by their absence.	An engine fails to make any noise thus indicating the secondary information about the flat battery
Metadata	Data that indicates the nature of some other (usually primary) data. They describe properties such as location, format, updating, availability usage restrictions and so forth.	The copyright note on the car's operation manual
Operational data	Data regarding the operations of the whole data systems	Computing logic that instructs the system to act in a certain way a in given condition.
Derivative data	Data that can be extracted from some data whenever the latter are used as indirect sources in search of patterns, clues or inferential evidence about other things than those directly addressed by data themselves.	One's whereabouts can be derived from where he/she use credit cards.

Table 1-3: Functional data types

1.3.2 Interpretations Adopted In This Research

During this research project, the author utilised concepts from this "informational map" to clarify positions on related concepts such as data, information and knowledge. Additionally, the author follows the common view of data as an element of information, and adopted an internal view for knowledge as internal phenomena to the human mind.

The interpretations on data, information and knowledge adopted in this research are outlined in the following:

1. *Data is an elemental building block of information.*
2. *Information is an umbrella term for all the concepts on the "informational map". Information consists of different types of data in different forms, served different functions, and can manifest into different types.*
3. *Knowledge is true information that is internalised as justified brief in the mind – the subjective domain as suggested by Zinc* (2007).

Moreover, the types of engineering information that were dealt with within this research project displayed the following characteristics:

- Form: They consist of data in *digital* form
- Type: They consist of data that form the following types of information
  - *Environmental information* – identity, activity, location, time,
  - *Semantic* – concepts and semantic relationships
  - *Information content* – factual and instructional data
- Function: They consist of data of the following functional type: primary data, meta data and derivative data

One of the deviation points of the above classification from Floridi's information map is the separation of semantic and content in the taxonomy of information types. This is for the consideration that: although information content would not mean anything without semantic, from a context aware point of view semantics are often needed to consider separately from content. Broadly speaking distinct research and development fields have developed from each of these categorise featuring different methods and specific techniques. This will be further addressed in Chapter 2.

Additionally, this research mainly dealt with information that engineers used to conduct knowledge work, but not how such information might be internalised as knowledge by these engineers.

1.4 Context and Context Aware Systems

In this section, the basic concepts related to context and context aware systems are introduced. This is to allow the reader to form an overall understanding of these two concepts that are core to the main technical subjects of this research. The concept of context is discussed in 1.4.1, followed by an introductory discussion on context aware systems in 1.4.2.

1.4.1 Context

In the following, the definition of context used by this research is presented, followed by a discussion on a classification of context.

Definition of Context

Generally speaking, the word "context" refers to information that can help to facilitate the understanding of some “core information” of interest. For example, the definition given by the Oxford Dictionary is "the circumstances that form the setting for an event, statement or idea and in term of which it can be fully understood" (Oxford Dictionary of English Second Edition Revised, 2009).

Research from different paradigms seems to address the definition of context quite different manners. Duranti and Goodwin pointed out (1992) that within particular traditions the concept “context” is defined more by “*situated practices, by use of the concept to work with particular analytic problem, than by formal definition*”. For example, context can refer to cultural setting, speech situation, shared background assumptions within which certain even is embedded.

The discussion of “context” in this thesis is to analyse phenomena related to creation and usage of information in aerospace knowledge work. Based on this, a formal definition of context from information perspective is considered to be appropriate. A widely used definition from context aware system research was provided by Abowd et al. (1999). They defined context as “*any information that can be used to characterise an entity*." In the scope of this research project, the author also adopts this definition of context.

It is obvious that the word "context" is inseparable from the word "information”, in that "context" serves the purpose of allowing certain “information” to be fully understood. One can also argue that the word “context” has the same semantic meaning as the word “contextual information”. Both words refer to information that can be used to describe some other information.

In the scope of this thesis, the research use “context” and “contextual information” interchangeably. The word “context” is used when the discussion is focused on topics closely related to “context aware system”. The word “contextual information” is used when the discussion is focused on certain information subjected to study.

Classification of Context

Another interesting topic related to context is to do with the question “what are the elements that constitute context”. For this, a good starting point is provided by Rudyard Kipling: "I keep six honest serving-men: they taught me all I knew, their names are what and where and when and how and why and who". From a more information system perspective, Abowd et al. (1999) identified time, location, identity and activity as the four fundamental context elements. Other have followed with similar suggestions, but also added elements according to the scope and focus of their research. A detailed review of these studies is presented in Chapter 2.

Since context (or contextual information) is a kind of information, with reference to the “information map” presented in 1.3, the proposed context elements generated by previous research can be regarded as contextual information for one of the three main types of structured information.

This gives rise to the three types of context that are considered relevant in this research, as shown in in the following.

- *Context of Information Content*: Context that originated from the nature or structure of information content.
- *Semantic Context*: Context that originated from information semantics according to which information is interpreted.
- *User Context*: Context that originated from the environment which information users operating in.

Specific context elements were then identified from the literature and classified accordingly into each type of context.

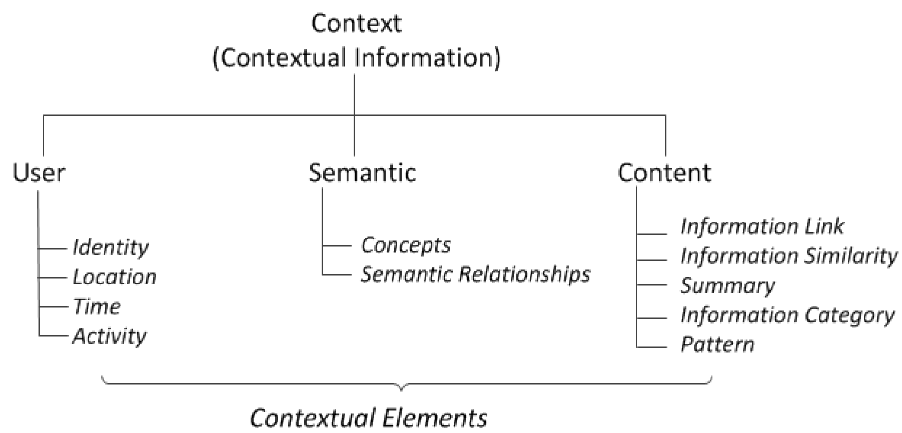


Figure 1-2: A classification of context

In the scope of this project, the focus was the context elements required for aerospace engineers to conduct aerospace engineering work. During the industrial study, these three types of context elements were used as a reference to identified context requirements for the engineering activities, as discussed in Chapter 4.

1.4.2 Context Aware Systems

Context aware systems are information systems that are "able to adapt their operations to the current context without explicit user intervention" (Baldauf, 2007). In the frame of this research, the term context aware system refers to information systems that apply techniques to capture and utilise the three type of context identified in 1.4.1

In the last decade, context awareness has been a focus point for research in the information technology area. This is evidently so in the increase of literature in this subject, as observed by Hong et al (Hong, Suh, & Kim, 2009). However, it is also clear that this notion of "context awareness" is widely used in a number of research fields such as ubiquitous computing (Chen & Kotz, 2000), knowledge representation and data analysis (Brezillon, 1999). As shown in Table 1-3, depending on the focus of the research, different context elements were suggested in different previous works.

To this extend, the specific techniques required to capture and utilise different types of context element are also different. In chapter 2, these different techniques are reviewed and appraised. They were then grouped into three categories of "context aware techniques". These are summarised as follows:

- *Profiling Techniques*: Technique that analyse user information by establishing profile that based on entities such as people, activity and object.
- *Semantic Techniques*: Techniques that analyse information semantic by modelling scheme and logical inference.
- *Data Mining Techniques:* Techniques that describe and analyse information content by applying advanced algorithms

This categorisation of context aware techniques was applied in the state of the art review on existing context aware systems of different origins, as discussed in Chapter 3. It is also used to as a reference to identify the technical scope of the experimental design and system development as seen in Chapters 6 and 7.

By leveraging context, context-aware systems are predicted to be able to provide adaptable interfaces, tailor datasets according to the application purpose, increase information retrieval precision, discover potential data service on the users behalf, understand user's implicit intention and help to build what can be thought of as a smart environment (Bolchini, Curino, Quintarelli, Schreiber, F.A, & Tanca, 2007).

To be able to provide these capabilities, they have to realize a set of process to capture and exploit targeted contextual information. Although details may vary, the following set of processes feature commonly in the literature:

1. *Context capturing* − use certain methods to capture context.
2. *Context modelling* − model and represent the captured context in a way that information systems can reason and act upon.
3. *Context reasoning* − perform reasoning according to certain logic based on the captured and modelled context to determine appropriate operation.
4. *Context utilisation* – Utilised the captured context to realise or support certain application based on the outcome of the modelling and reasoning process.

Among existing research, much work was focused on the concept and research topics including context modelling and reasoning (Hong, Suh, & Kim, 2009), this is especially the case for less mature techniques in the *semantic techniques* category. It has been observed that more work is needed to understand topics related to potential usage of context aware systems in a commercial setting (Brown, Bovey, & Chen, 1997). For example, how to provide an integrated approach to facilitate context capturing (Uren, et al., 2006)? How to evaluate the performance of context aware system (Hong, Suh, & Kim, 2009)?

The main research topic of this project − the application of context aware systems to support knowledge work falls into this under researched area. With relation to the four processes listed above, this research project started with a generic focus on the each of these during the investigation phase. The focus was then shifted toward context capturing and context utilisation during experiment phase. These two distinct phases of research activities are discussed in detail in 1.6.

1.5 Research Aim and Objectives

It is thus possible to outline the initial research aim for this project. The overall research aim was to *investigate the application of context aware systems to capture and utilise context to support knowledge work in the aerospace industry*. This also aligns with the interest of Airbus, as the sponsoring company and the host of the research venue.

This overall research aim was to be eventually fulfilled by undertaking research activities that contributed to the following four research objectives:

- **Research Objective 1**: To understand the state of art in research, development and application of context aware systems.

- **Research Objective 2:** To understand the nature of context in the aerospace industry.
- **Research Objective 3:** To investigate a cost-effective approach to capture domain context.
- **Research Objective 4:** To explore the application of context aware systems to support aerospace knowledge work in operational settings.

The research project started with research objective 1 and research objective 2. As the research work progressed from investigation to experiment and system development, as described in 1.6, key research topics were identified for further investigation. Research Objective 3 and Research Objective 4 were then added to this research project to reflect the specific research direction taken in the experiment phase. The analysis performed to review the list of research objectives is presented in Chapter 5.

1.6 Research Methodology

The industrial nature of this project had a degree of impact on the research methodology that was applied in that it provided a genuine “laboratory” for evaluation. The aim of this research is about applying technology specifically on the aerospace industry, and the research was 80% based in Airbus. This level of industrial immersion, although did not prevent the author conducting cross-sectional investigations as seen Chapter 2 and Chapter 3, it did allow author the opportunity to perform longitudinal study focused on specific engineering activity.

The industrial setting of this study also had an impact on how the experiments were designed and carried out. The research aim determined that a key success factor of the project was demonstration of the impact of the deployed solution on the local business operation setting as well as validating the research proposals. In order to ensure the adoption of the deployed system, and also to gather required data to demonstrate such impact, the experimental execution period of this project lasted for 18 months. Given the resource and time required to perform this, it was not possible to include more than one engineering use case in the experiment execution and system deployment period.

The research methodology of this project was loosely based on the Design Research Methodology developed by Blessing and Chakrabarti (2009). The outline of this methodology is shown in the Figure 1-3 below:

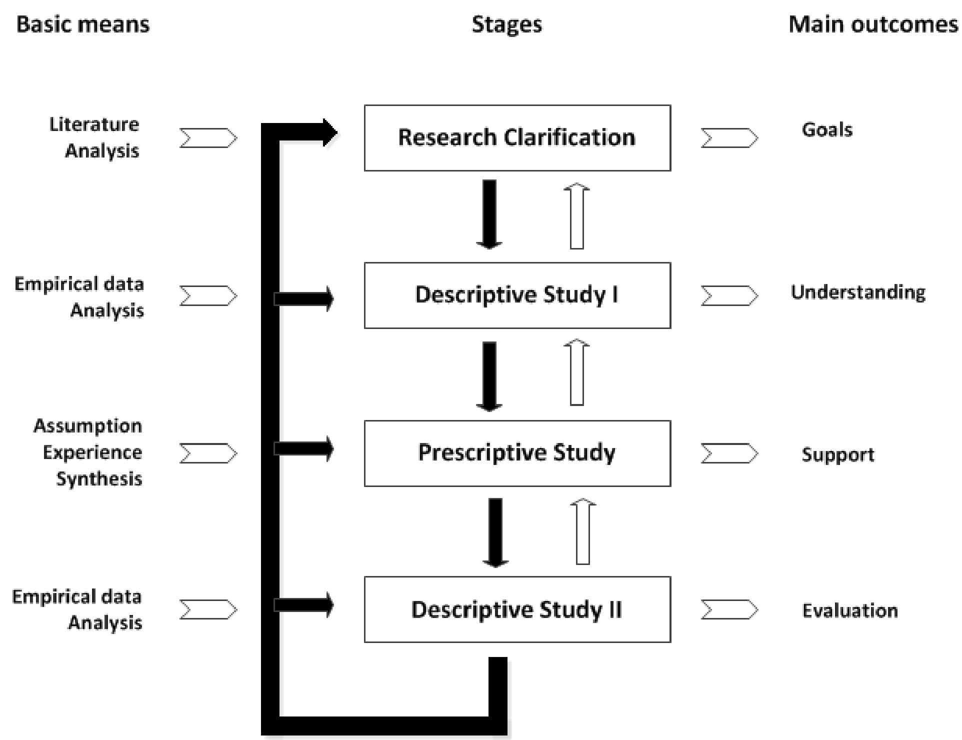


Figure 1-3: DRM Framework (Blessing & Chakrabarti, 2009, p. 15)

As shown in the figure above, the DRM as proposed by Blessing contained the following four stages:

- *Research Clarification:* The focus of this stage is to clarify the aim and objectives of the research; the basic mean is by performing review on the literature.
- *Descriptive Study I:* The focus of this stage is to perform in-depth study to identify detailed and measurable criteria with which the research can be objectively assessed.
- *Prescriptive Study:* The focus of this stage is to design an experiment and develop required tool or methods, so that the desired situation or output can be realised.
- *Descriptive Study II:* The focus of this stage is to perform a formal evaluation of the experiment output with the identified criteria, so that conclusion can be reached on whether the desired research outcome has achieved.

Based on the specific industrial setting and the investigation subject of this project, the DRM methodology was adapted as the shown in Figure 1-4 below:

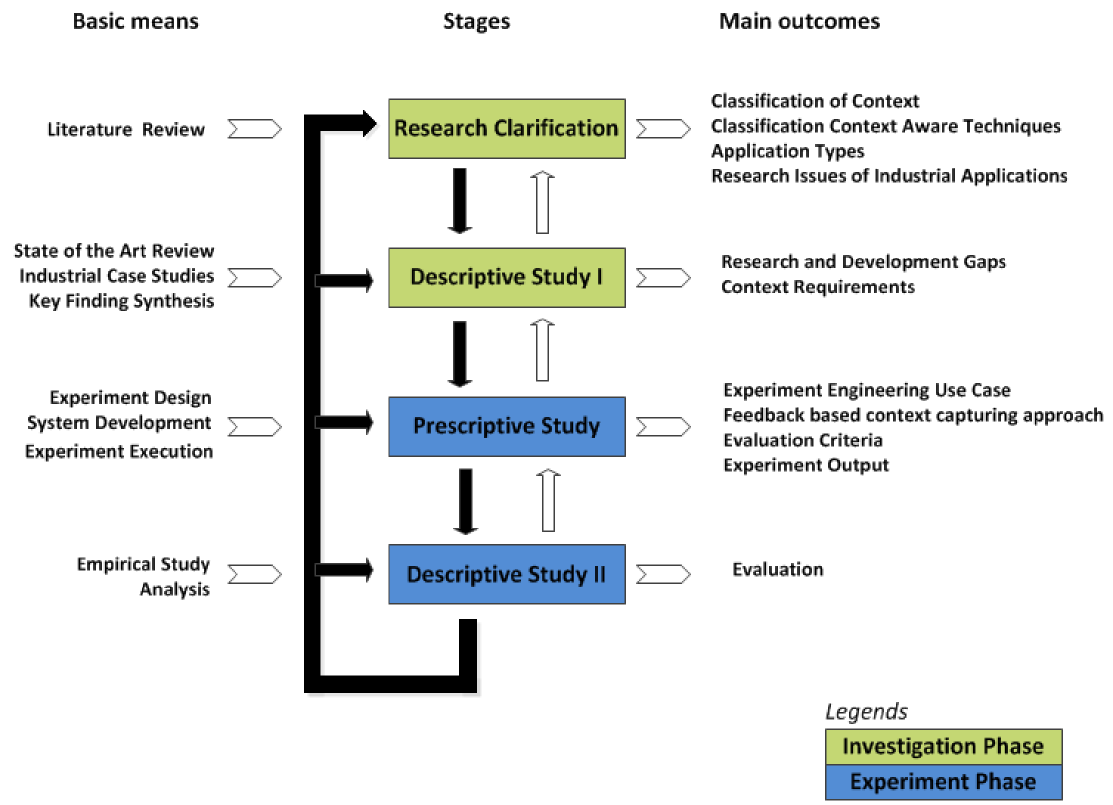


Figure 1-4: Research methodology of this research

As seen Figure 1-3, the research methodology of this research contains the same four stages of the original DRM framework. Additionally the research activities are grouped into two distinctive phases: an investigation phase and an experiment phase. This grouping is based on the different nature of the activities between the two phases. Within the investigation phase, the research activities were focused on investigated oriented activities to understanding existing state of the art and industrial practices. Within the experiment phase, the focus switched to the design, development, experiment and evaluation activities which were more technical oriented.

Because of the industrial nature of this project, it was possible to conduct a number of industrial related pilot studies. These were pivotal before the complete set of research objectives could be clarified. For this reason, with comparison to DRM, the research objectives could only be revised after the "descriptive study I" study.

In the frame of this research, in order to evaluate the impact of context aware systems on knowledge work, the evaluation criteria need to be related to the key activities of the engineering use case featured in the experiment. In this case, it is the repair case search efficiency of the engineers. As seen in Chapter 6, the evaluation criteria could only be determined after the experiment use case was defined. For this reason, as opposed to the DRM framework, the evaluation criteria could only be defined after the "Prescriptive Study" stage.

Finally, in order to ensure each of the identified research objectives could be address, research activities listed in Figure 1-3 were associated with the research objectives they contribute to. This is outlined in the following Table 1-4

Research Objective	<u>Research Activities</u>
RO1: **To understand the state of art in research, development and application of context aware systems in academic, public and industrial domains.**	- Literature review on related research areas - State of the art review on context aware systems
RO2: **To understand the nature of context with relation to engineering knowledge work in the aerospace industry.**	- Case studies of aerospace engineering activities - Experiment to capture and utilise domain context - Empirical study and evaluation
RO3: **To investigate the how engineering domain context can be captured in a cost-effective manner.**	- Experiment design - Experiment to capture and utilise domain context - Empirical study and evaluation
RO4: **To explore the application of context aware systems to support aerospace knowledge work in an operational setting with collaborating business department.**	- Experiment design - System development for Daedalus - Experiment to capture and utilise domain context - Empirical study and evaluation

Table 1-4: Research Objective vs. Research Activities & Outputs

1.7 Thesis Layout

The thesis layout from Chapter 2 to Chapter 9 are presented in Figure 1-5, this figure shows the logical linkage between these chapters, as well as how key research output contributing to the research objectives are included throughout the thesis

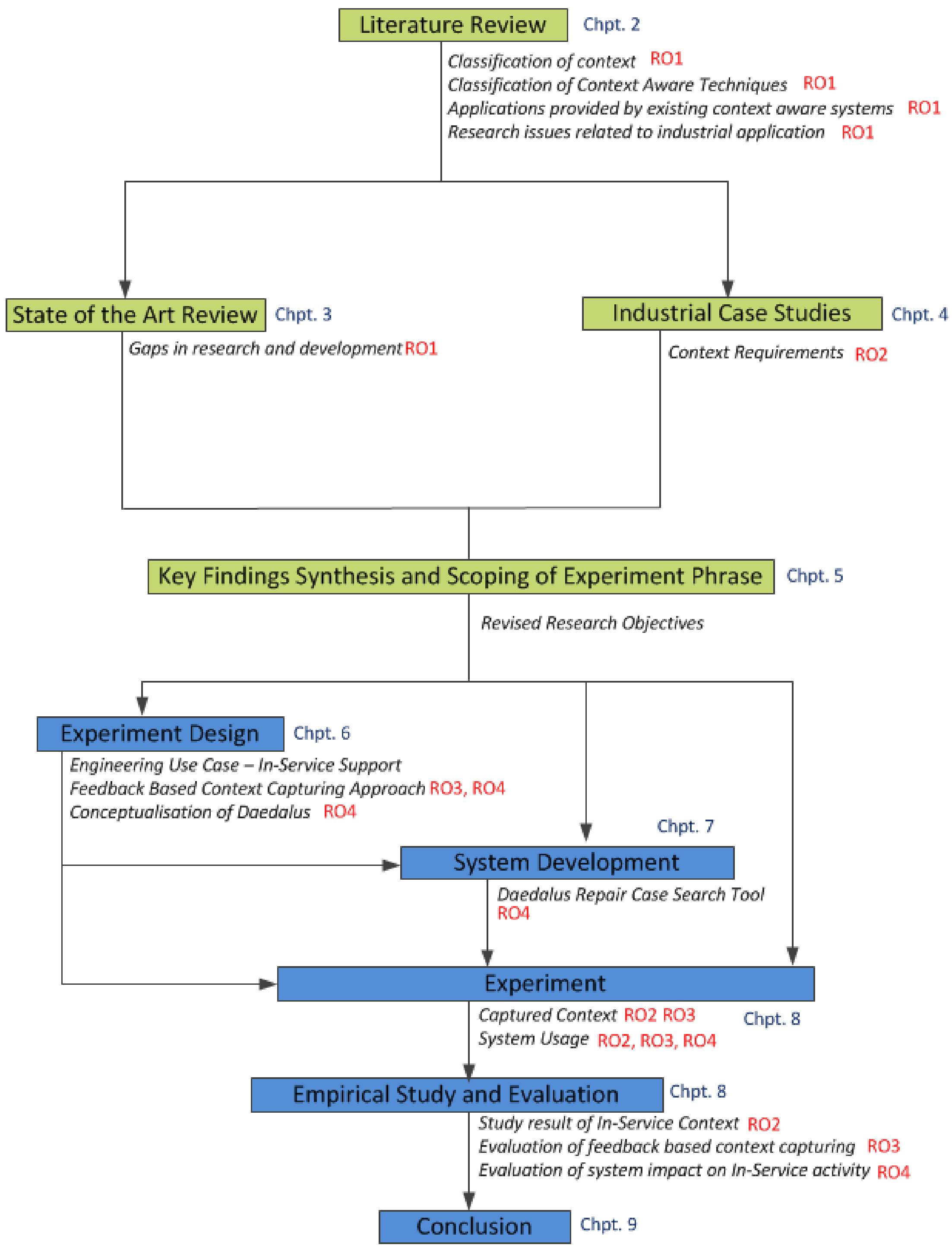


Figure 1-5: Thesis layout

As shown in the above figure, the investigation phase contains: literature review as presented in Chapter 2, the state of the art study as presented in Chapter 3, and an industrial case study on engineering practices as presented in Chapter 4. Synthesis analysis of key findings of the investigate phase as presented in Chapter 5. After the key findings are synthesised, the research objectives were revised.

In the experiment phase, the following research activities were undertaken: the design of experiment to capture engineering context using the feedback based approach as presented in Chapter 6, the development of context aware repair case search tool Daedalus as presented in Chapter 7, key events and outcome of the experiments, empirical studies and evaluation activities are then presented in Chapter 8. Finally, the conclusion of this thesis is presented in Chapter 9.

2 Literature Review

This chapter presents a review of literatures that analyses the nature of context, as well as on the research work that focusses on developing intelligent capability that make use of such context. The word context, therefore, is used here to refer to “contextual information” that “characterise” certain information entity, be it a document, a folder, or an information repository. Such "contextual information" serves to aid the understanding of information. This is the first of three chapters which cover research activities in the investigation phase: the research literature (Chapter 2), the state of the art of the systems (Chapter 3) and the requirements of using context in knowledge work in aerospace industry (Chapter 4).

In Section 2.1, the concept of context and context element is addressed. A classification of context is presented to represent different types of context that relevant to engineering knowledge work. Furthermore, a review of context elements within to each type of context is also presented in this section. An overall discussion of context aware systems is presented in Section 2.2 to introduce key capabilities of context aware systems and key process that need to addressed to provide context aware capabilities.

From Section 2.3 to 2.5, in-depth reviews are presented to cover key aspects of context aware systems. Techniques that were applied to deal with different type of context, referred to as context aware techniques, are reviewed in Section 2.3; Application provided by existing context aware systems to support knowledge work are reviewed in Section 2.4; Research issues related to industrial application of context aware systems are reviewed in Section 2.5.

2.1 Context and Context Elements

As mentioned in Chapter 1, in the scope of this research, the definition adopted for context is that “*any information that can be used to characterise an entity*" (Abowd, et al., 1999). Specifically, the context in this research refers to any information that can be used to characterise information required in aerospace knowledge work.

According to Floridi’s the “information map”, as shown in Figure 1-1, information can be considered to exist in three types: Information content, information semantic, and information environment. Since context is also information, the same classification can be applied. Additionally, the focus of this research is on context of engineers who use information in a stationed desktop environment. For this research, the environment context that is of interest is that of digital information user. Therefore, the following three type of context are addressed in this research.

- *Context of Information Content*: Context that originated from the nature or structure of information content.
- *Semantic Context*: Context that originated from information semantics according to which information is interpreted
- *User Context*: Context that originated from the environment which information users operating in.

Still, the perception of what constitute as context is blurred and often depends heavily on what the information is to be used for and how it is to be used. Additionally, depending on the intended application, the nature of contextual information investigated varies greatly. As a result, different research identified different elements that context might be consisted of. For example, in the two industrial case studies described in Chapter 4, domain semantic is considered to be important for the In-Service department for repair case search consistency, while user identity are considered to be critical for access control for lessons-learnt document.

In order to take account of what constitute as context in a prescriptive manner, the term "context element" is used in this thesis to refer to elemental information that combine and form what is perceived as context. In subsections 2.1.1 to 2.1.3, according to classification of context presented above, a review is presented for context elements that were identified within each type of context.

2.1.1 Context of Information Content

From information users point of view, mostly the concept of information content (i.e. main body of a documents) refer to the part of information object which is of particular interest to users, and therefore serve as the main focus on information related activities, helping to facilitate understanding and form new knowledge.

However, it is also commonly understood that certain implicit parts of information content, if captured, processed and utilised appropriately, can be used to greatly increase the efficiency of information activity. Such "implicit information" is often regarded as context by previous researches (Sciore, Siegel, & Rosenthal, 1994; Bhandari, et al., 1997; Goh, Bressan, Madnick, & Siegel, 1999) in the field of context aware systems. In the literature review, the following context element were identified from these previous researches and classified as context from information content: information link, similarity, summary, information category, and pattern.

Information Link

The term information link refers to information linkage that indicates connection between information objects. Typically, information links that are identified in the information content are regarded as explicit link, such as hyperlink between webpages (Page, Brin, Motwani, & Winograd, 1999) and reference between academic papers (Giles, Bollacker, & Lawrence, 1998). Those that are not explicitly identified and therefore required certain analysis technique are regarded as implicit link, such as documents that could be identified as linked by analysing user behaviour (Xue, et al., 2003) or query log (Radlinski & Joachims, 2005).

Information Similarity

The term information similarity refers to the similarity between content of two or more information objects. Such similarity can be measured from different perspective, such as string comparison (Yianilos & Kanzelberger, 1997), word distance (Kozima & Ito, 1997), key words similarity (Terra & Clarke, 2003) and semantic similarity (Resnik, 1995).

Summary

The term summary refers to a brief and concise body of text which condense the meaning of certain information content. An appropriate summary would often help information user to quickly establish understanding of information by generate summary from single (Kupiec, Pedersen, & Chen, 1995) or multiple (Goldstein, Mittal, Carbonell, & Kantrowitz, 2000) information objects. Meanwhile, such summaries can be generated in the form of key words (Matsuo & Ishizuka, 2004) or abstracts (Johnson, Paice, Black, & Neal, 1997).

Information Category

When presented a number of information objects such as documents or webpages, it is often desirable to categorise these information objects into a smaller number of categories for organisation or distribution purpose. Such categorisation could be taken from different perspectives such as specific key words (Mase & Tsuji, 2001), pre-determined classifications schemes (Varma, 2007) or clusters of specific topics (Tkach, 1998).

Pattern

It is often desirable from information user perspective to utilise pattern to handle information. This could include specifying certain pattern for information search (Etzioni, et al., 2004), identifying previous unseen pattern from large body of information objects (Zhu, Nie, Liu, Zhang, & Wen, 2009), or arranging unstructured information (Cafarella, Halevy, Wang, Wu, & Zhang, 2008).

2.1.2 Semantic Context

The term "semantics" often refers to "*the branch of linguistics and logic concerned with meaning*" (Oxford Dictionary of English Second Edition Revised, 2009). From an information technology perspective, Information semantics is often regarded as context under which certain information is interpreted. For example, the concept "Bull" in the context "Animal" refers to the male of a bovine animal, while in the context "Stock" refers to increasing stocks. Researches that sought to leverage information semantics for advanced capabilities often address information semantics in terms of concepts and relationships between concepts. These are discussed in the following text.

Concept

The term concept refers to notions that are used within semantics of certain domain. In such domains semantics, the collection of concepts forms the vocabulary which individuals used to exchange and share information. In researches related to information semantics, the key issue is to relate the "word forms" of concepts to their "word meanings" in various domains (Miller, Beckwith, Fellbaum, Gross, & Miller, 1990), so that computing entities (i.e. information systems) can also interoperate "*meaningful content*" from information objects such as webpages (Berners-Lee, Hendler, & Lassila, 2001).

Relationship

In the frame of this research, the term relationship refers to relationships between concepts from a semantic sense. In another word, if the meanings of two concepts are related, then these two concepts are said to be "semantically related". In existing literature, many forms of such semantic relationships have been addressed, such as synonym, acronym, hyponym, hypernym, meronym and holonym (Mangold, 2007).

The distinction of "word forms" and "word meanings" above were particular relevant to this research. At discussed in Chapters 6, 7 and 8, the experiment phase involved the following activities: 1) the profiling of search term by engineers; and 2) capturing semantic context from such profiled data in a context model. While interpreting this experiment data, the search terms were regarded as articulation of domain semantic context by engineers. These search terms were therefore considered to the "word forms" of domain semantic context; while the "concept" and "relationships" as captured in the *Context Model* were consider as "word meaning" of such semantic context.

2.1.3 User Context

User context includes any type of contextual information that can be used to characterise the environment users operating in when information related act ivies take place. Such activities can be any activities across the information lifecycle (Floridi, 2010, p. 5) namely creation, collection, storage, process, distribute, consume and erase. The entities who undertake such activities can be both human actors and computing entities.

As to what information shall be considered as elements that constitute such context, a wide range of items had been proposed by previous researches. This research adopted the context elements that are proposed by Abowd et al. (1999): time, location, activity, identity. Review was then taken place to map context elements used in other previous research into these for types of context element. These are discussed in the following.

Time

This context element is used to represent the temporal information related to the information of interest. Different aspects related to time are also often considered in the literature, such as time zone (Barkhuus & Dey, 2003) and duration (Strang, Linnhoff-Popien, & Frank, Applications of a context ontology language, 2003). Additionally, context history – the historical information on how context changed overtime is often a subject of investigation (Zimmer, 2004).

Location

This context element is used to represent the locational information related to the information of interest. Such locations could be physical location in both absolute (Chen, Finin, & Joshi, 2003) or relative terms (Jones, Abdelmoty, Finch, Fu, & Vaid, 2004), but can also refer to digital location such as website address (Wolber, Kepe, & Ranitovic, 2002) or certain point in a file structure (Gyllstrom & Soules, 2008).

Activity

This context element is used to represent activities that are related to the information of interest. An activity could be specific physical actions such as "a mouse click" or a conceptual action such as "opening a digital document" (Campbell, Culley, McMahon, & Poleman, 2005). It could also represent a task which might comprise with a series of activities (Kersten & Murphy, 2006).

Identity

This context element is used to represent information that can be used to characterise information users. Such contextual information can be related to individual (Sieg, Mobasher, & Burke, 2004), groups (Wang, Bodily, & Gupta, 2004), or computing devise that is interacting with users (Celentano & Gaggi, 2006).

2.1.4 Conclusive Remarks

Based on the review presented from 2.1.1 to 2.1.4, a classification of context was applied in this research with three types of context, and with the context elements outlined below and also shown in Figure 2-1:

- *Context of Information Content*: information link, information similarity, summary, information category, pattern
- *Semantic Context:* concepts, semantic relationships
- *User Context:* identity, location, time, activity

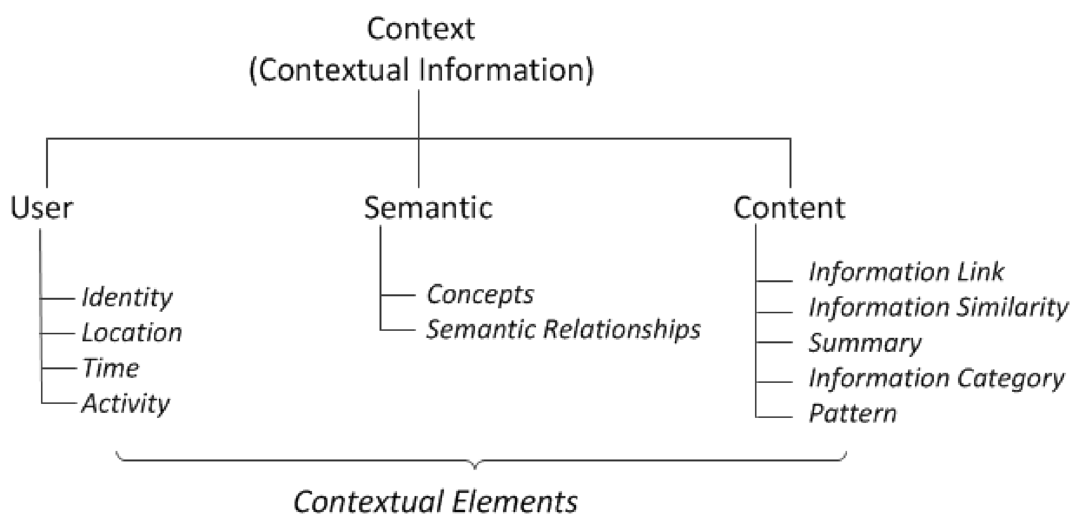


Figure 2-1: A Classification of context

In existing literature, various context aware techniques are used to deal with each context elements identified in this classification of context, these are addressed in 2.2.

2.2 Context Aware System

Context aware systems are information systems that are “able to adapt their operations to the current context without explicit user intervention” (Baldauf, 2007). In this research, the term “context aware system” particular refer to information systems that adapt their operation to the three types of context identified in 2.1.

Bolchini (Bolchini, Curino, Quintarelli, Schreiber, F.A, & Tanca, 2007) identified the main capabilities of context aware systems as the following: providing adaptable interfaces; tailoring dataset according to the application purpose; increasing information retrieval precision; discovering potential data service on users’ behalf; understanding user’s implicit intention and helping to build what can be thought of as a smart environment.

To realise these capabilities, context aware systems need to perform a set of processes to handle context of the situation of interest. For example, in the context toolkit, Dey et al. (2001) proposed an architecture that can allow context storage, context interpretation, and context sharing. In another interpretation, Chen and Kotz (2000) identified the two key processes of sensing and modelling context, before such context can be applied. In a state of the review on context aware systems for knowledge management, Dormon et al. (2007) identified four tasks as: context gathering, context modelling, and context inference and context functionality. By converging and referencing to these previous researches, the following four processes are identified and used in this research:

1. *Context capturing* − use certain methods to capture context.
2. *Context modelling* − model and represent the captured context in a way that information system can reason and act upon.
3. *Context reasoning* − perform reasoning according to certain logic based on the captured and modelled context to determine appropriate operation.
4. *Context utilisation* – Utilised the captured context to realise or support certain application based on outcome of the modelling and reasoning process.

Table 2−1 below shows how these four key process matches to various interpretations used in previous research:

Key processes	**Dey et al. (2001)**	**Chen and Kotz (2000)**	**Dormon et al. (2007)**
Context Capturing	Storage	Capturing	Capturing
Context Modelling	Interpretation	Modelling	Modelling
Context Reasoning			Inference
Context Utilisation	Sharing	Application	Functionality

Table 2-1: Key processes to handle context

From Section 2.3 to 2.5, in-depth reviews are presented to cover key aspects of context aware systems. It is worth pointing out that, for each of these key aspects, a given context aware system often corresponds to multiple elements. For example, different context aware techniques can be applied in the same system to capture, model, reason and utilise context. Similarly, the same system can provide multiple types of applications to provide multiple support functions to knowledge work. To this end, the specific inter-relationships between different aspects of context aware system − such as how key process to handle context might be mapped to key functions to support knowledge work − are of complex nature. For the sake of simplicity, the author chose not to further elaborate on these relationships. Nevertheless, detailed information for each specific systems that were reviewed are provided in Appendix A.

2.3 Context Aware Techniques

In Section 2.1, a classification of context is presented with three main context types and context elements in each type of context. In existing literature, various techniques had been applied to leverage these different types of context – by capturing various context elements, performing required modelling and reasoning tasks, and utilise them. These techniques will be referred to as “context aware techniques” in this thesis in that it is by applying these techniques that various capabilities of context aware system are realised. Additionally, the reviewed techniques are classified into three categories, these are:

- *Data Mining Techniques*: This category includes techniques mainly focus analysing information content.
- *Semantic Techniques*: This category includes techniques mainly focus on handling concepts and relationships been concepts
- *Profiling Techniques*: This category includes techniques mainly focus on capturing contextual information from information users.

Under each category, types of specific techniques were identified. Each type of specific techniques was applied to leverage similar contextual information. Although not all previous researches can be clearly classified in one of the three categories, broadly speaking distinct research and development fields have developed from each of these category featuring different methods and specific techniques. In the following, from 2.2.1 to 2.2.3, techniques from each category are discussed.

2.3.1 Data Mining Techniques

Traditionally, techniques that describe and analyse information content mainly consist of automatic or semi-automatic approaches originated from fields such as information processing and optimization from as early as the 1970s (Han, Kamber, & Pei, 2006, p. 2). Increasingly, the term data mining has been used to refer to a blend of concepts and algorithms from machine learning, statistics, artificial intelligence, and data management (Harding, Shahbaz, Srinvas, & Kusiak, 2006).

From a context perspective, these techniques seek to identify useful contextual information from information content by using automatic inferring. In the review, the following specific groups of techniques are identified: text analysis, link analysis, static grouping, dynamic grouping and pattern analysis. Detailed discussion for each type of specific technique is presented in the following text.

Text Analysis

There is a large body of existing work on how best to extract contextual information from textual content to facilitate more efficient understanding for information users. Existing researches that seek to extract indicative and contextual information apply technique such as nature language processing (Yi, Nasukawa, Bunescu, & Niblack, 2003), static heuristics (Seifert, Welch, & Komisarczuk, 2008), Bayesian probabilistic model (Daume III & Marcu, 2006), and Graph theory (Washio & Motoda, 2003).

The presentation of such contextual information can help to reduce the mental load on the user (Chang & Hsiao, 2008), this in term improved efficiency in both information retrieval (Xu & Croft, 2000) and understanding (Gephart, 1997). Various systems have been proposed to generated auto-summary (Salton, Allan, Buckley, & Singhal, 1996) and key words information in various forms (Vaithyanathan, Adler, & Hill, 1999; Viegas, Wattenberg, & Feinberg, 2009) .Additionally, these type of text analysis technique are also applied to measure information similarity (Sahami & Heilman, 2006).

Link Analysis

Link analyses are techniques used to identify potential links or relationships between different information objects. One example is the PageRank algorithm (Page, Brin, Motwani, & Winograd, 1999), which analysed the "relevancy" between documents by applying link analysis technique. Another example is that of HITS (Gibson, Kleinberg, & Raghavan, 1998) algorithm which attempts to identify documents with high authority weigh.

With more focus on implicit link such as academic paper citation, Giles et al (1998) apply a combination of word vector and string similarity methods to determine the similarity between papers in additional to identifying dependency between objects. Alternative approach to identify implicit links methods such as including monitoring user access patterns (Xue, et al., 2003) and using affinity graph (Zhang, et al., 2005).

Information Classification

In additional to identifying dependency between objects, newer generation of information retrieval services also attempt to reduce the cognitive task information users face in navigating and choosing retrieval results. Specific technique to achieve information classification includes application of algorithms such as decision tree induction (Ding, Qin, & Perrizo, 2002), rule based classified (Chen & Wang, 2003) and vector machines (Han, Kamber, & Pei, 2006). Advanced algorithm such as those support text analysis, as mention above, are applied to perform automatic analysis on the targeted information content.

Increasingly in the last decade, semantic techniques such as semantic representation are being applied to provide such information classification scheme in the form of taxonomies (Weng, Tsai, Liu, & Hsu, 2006; Li & Roth, 2006). These semantic techniques will be discussed in detail in 2.2.2.

Research project such as the waypoint system (McMahon, et al., 2004) used a semi-automatic manner with combine series of expert-generated taxonomies with automatic search based on taxonomy chosen by the user. Alternatively, other researches applied automatic technique to generate the classification scheme by extracting tabular information (Cafarella, Halevy, Wang, Wu, & Zhang, 2008), applying self-learning algorithm (Yates, et al., 2007) and genetic programming (Hirsch, Saeedi, & Hirsch, 2005).

Information Clustering

Compared to information classification described above, information clustering is a type of specific techniques that seek to categorise information in a more dynamic manner. This is achieved by applying algorithms such as hierarchical clustering models (Sheth & Tormen, 2002), K-means (Ahmad & Dey, 2007), C-means (Yu, Hu, & Bao, 2004), distribution models (Fraley & Raftery, 2002) to perform automatic classification scheme generation. As semantic technique becoming more mature, there is also increasing amount of research work that seek to incorporate semantic representation into generation of information clusters (Sheikholeslami, Change, & Zhang, 2002; Kuhn, Ducasse, & Girba, 2007)

Within the existing literature, application of information clustering techniques include some of the following: generating automatic semantic annotation (Black, et al., 2005; Black, et al., 2005); providing navigation support to information search results (Koshman, Spink, & Jansen, 2005; Zhu, Nie, Liu, Zhang, & Wen, 2009); facilitating information push (Dormon, Lakshmanan, & Nuzzo, 2007).

Pattern Analysis

Pattern analyses are techniques that applied to identify previously unseen pattern or match pre-determined pattern from large of data. This include applying methods such as template matching (Fu, Chung, Luk, & Ng, 2007), statistical algorithms (Belz & Mertens, 1996), and neural network (Mao & Jain, 1995).

For example, Horvitz (Horvitz, Breese, Heckerman, Hovel, & Rommelse, 1998) applied Bayesian network to evaluate patterns in event data. The WebTable system mentioned above applied syntactical analysis techniques to construct the information classification scheme (Cafarella, Halevy, Wang, Wu, & Zhang, 2008). Caskey (2001) applied neural network to analysis data structure for manufacturing problem solving.

2.3.2 Semantic Techniques

The rise of collaborative intelligence enabled by web 2.0 platform brought huge volume of user-input information. The unstructured and distributed nature of such information highlight the need for next generation information system to be able understand such user generated information from a semantic perspective and "*carry out sophisticated tasks for users*" (Berners-Lee, Hendler, & Lassila, 2001). Increasingly, efforts to overcome such semantic issues centre on semantic techniques that leverage semantic context of information.

These techniques seeks to capture and encode meaning separately from information content, and represent such meaning in semantic representation that can be interpreted and shared by information systems . The term "semantic representation" here refers to representation of semantic context in formats ranging from simplistic concept list to comprehensive context model.

Torre (Torre, 2009) proposed two types of semantic techniques: strong semantic techniques represent modelling and reasoning techniques that are often under discussion in semantic research; week semantic techniques represents any combination of techniques that somehow "bring meaning" to information.

In this research, the author took the position that the term "semantic techniques" shall refer to techniques that apply either strong or weak semantic technique or any combination of these two categories. In the following four type of specific semantic techniques identified from the literature are discussed.

Simplistic Semantic Representation

The term "simplistic semantic representation" here refers to any techniques that applied simplistic formats to capture information semantics in forms of key-value models or mark-up scheme models (Strang & Linnhoff-Popien, A context modeling survey, 2004). The simplistic formats here refer to any scheme that either followed basic standards such as XML or HTML, or implemented based on self-defined format. Typically this type of techniques don't accommodate context inferring capabilities, and therefore belong to week semantic techniques as classified by Torre (Torre, 2009)

Among existing literature, this type of techniques had been applied in areas such as enhancing basic text-based search (IBM, 2013), creating online language source in lexical format (Miller, Beckwith, Fellbaum, Gross, & Miller, 1990), and annotating engineering information (Verhagen, et al., 2012).

Resource Description

Resource description techniques take the view that concepts in a given semantic domain can be described as entities with descriptive information. Such descriptive information then also includes relationships with other entities. The most noticeable standard of resource definition is the RDF (**R**esource **D**escription **F**ramework) promoted by W3C (W3C, 2004). The RDF standard also provided reasoning mechanism such as SPARQL (**S**imple **P**rotocol and **R**DF **Q**uery **L**anguage) (W3C, 2008), although implementation of such mechanism is not compulsory. Similar to RDF, standards that allow similar resource description include DCMI (**D**ublin **C**ore **M**etadata **I**nitiative) (DCMI, 2011) and irON (**i**nstance **r**ecord and **O**bject **N**otation) (Mergman & Giasson, 2011).

In recent years, there had been numerous research and actual development using resource description techniques. Corby et al. applied RDF to facilitate information retrieval in the Corese search engine (Corby, Dieng-Kuntz, & Faron-Zucker, 2004). Amaya (Quint & Vatton, 1997) is a system that allows semantic annotation to be created. OpenCyc (Sicilia, Garcia, Sanchez, & Rodriguez, 2004) is an attempt to create a knowledge based with data in RDF format to be easily integrated by information systems.

Ontology Modelling

Compare to semantic techniques mentioned above, ontology modelling is more elaborated both in terms of creation process and the inherent structure, but offer richer capabilities. Ontology standards such as OWL (Web Ontology Language) (W3C, 2007) and DAML (**D**ARPA **A**gent **M**arkup **L**anguage) (DAML, 2006) often provide dedicated ways to identify classes specify different relationships and create instances. Many attempts to apply ontology modelling also implement reasoning mechanism using such as descriptive logic. This is discussed in the “Context Inference” part of this section.

Areas of application of ontology modelling techniques are similar to that of RDF. In the knowledge sifter systems, Kerschberg (Kerschberg, et al., 2004) proposed a knowledge discovery approach with user query being reinterpreted by concepts from multiple ontologies. Enterprise search system such as Vivisimo allowed ontology model to be integrated to support search functionality (Doms & Schroeder, 2005). Text2Onto (Cimiano & Volker, 2005) is a system that generate ontologies by learning from text based information.

In the emerging field of ubiquitous computing, ontology modelling techniques had also been applied to capture environmental context of information. For example, CONON (Wang, Zhang, Gu, & Pung, 2004) is an approach for modelling context of activities, person, locations and computing entities using both generic and domain specific ontologies. Cobra (Chen, Finin, & Joshi, 2003) is architecture to allow software agents to perform reasoning based on context of people, place and intention.

Context Inference

As mentioned above, both resource description and ontology modelling techniques allow reasoning mechanisms. These reason mechanism, referred to as "context inference" in this thesis, allow application of logic to perform reasoning based on relationships between related concepts. Such reasoning can therefore identify "*implicit context*" that is not explicitly stated in the context model (Wang, Zhang, Gu, & Pung, 2004) and guide information system behaviour.

Within existing literature, some of the applications of context inference include recommendations of personalised TV content (Fernandez, Arias, Nores, Solla, & Cabrer, 2006), support context-aware services (Henricksen & Indulska, 2004; Ejigu, Scuturici, & Brunie, 2007) and smart locations (Al-Muhtadi, Ranganathan, Campbell, & Mickunas, 2003).

2.3.3 Profiling Technique

Information users play a central role in any scenario of information usage, influencing potential value any information can offer in given circumstance. the same document is often more important to one user than another due to difference in users' background, preference, short and long term information needs. For this reason, leveraging the context of information users is of vital importance to systems or applications that display intelligent capability.

The task to leverage user context is often referred as user profiling or user modelling. The two terms of user profiling and user modelling are often inter-usable. For example, Benyon and Murray (Benyon & Murray, 1993) defined a user model as a representation of knowledge and preferences of users, while Schiaffion and Amandi broadly refer to both as essential information about individual user (Schiaffino & Amandi, 2009).

For clarity purpose, the term user profiling will be used here. Specifically, the literature covered in this part regarding user profiling relates to what Biswas and Robinson refer to as "Application Specific Models" − approaches that maintain a user profile and use different types of AI systems to predict performance (Biswas & Robinson, 2010). The techniques that are applied to perform this user profiling task are referred to as "profiling techniques" in this thesis.

Activity Profiling

The term "activity profiling" here refer to techniques that seek to capture user's context by monitoring users' activities. In the frame of this research, the type of user activities concerned is users' activities operating information systems. The purpose of activity profiling can be either to capture such context for long term future usage, or change information system behaviour to adapt to user's short term need (Campbell D. R., 2007, p. 1.20).

Nevertheless, for both purposes , activity profiling techniques applied in previous works focus on capturing a wide range of implicit indicators (Claypool, Le, Wased, & Brown, 2001): specific action from users that might indicate certain user context; Information viewing time can be related to user's interest and preference for information; Citation action to another document would indicate potential link between information objects (Oard & Kim, 1998) . Such implicit indicators are then analysed by applying data mining techniques such as information clustering (Oberle, Berendt, Hotho, & Gonzalez, 2003) and pattern analysis techniques (Van Velie & Traetteberg, 2000), so that implicit context such as dependence between items and action pattern can be identified.

For example, the systems CIFLEX (Campbell D. R., 2007, pp. 7.2 -7.18)and Watson (Budzik & Hammond, 1999) captures user's action at file manipulation, web browsing activities, file viewing and editing time. This is to calculate "contextual dependencies" between stored information and user's current action, so that information of high dependency score can be pushed to the user. Alternatively, Gyllstrom and Soules (2008) proposed an approach to profile users activities by only tracking text or images viewed by users from the interface, and therefore allowed users to retrieved specific content instead of individual documents. Additionally, methods that monitor implicit indicator allow understanding of individual characteristics such as learning style (Lee M. G., 2001; Froschl, 2005) as well as profiling of interaction preference (Weakliam, Bertolotto, & Wilson, 2005).

Physical Sensing

Physical sensing referred to techniques that capture user context from the physical world such as time, location and biological information. These are mainly achieved by using sensory hardware. Although sensory technology were out of the scope of this research, the handling of such context is subjected to increasingly attention from context aware system researches in the last decade due to the rise of ubiquitous computing (Accenture, 2010).

In existing literature, the key applications of these techniques are on areas such as smart space, tour guide, information systems, communication systems, M-commerce and Web service (Hong, Suh, & Kim, 2009). Many of these applications applied physical sensing techniques to capture and utilise context, and use the semantic techniques described above for context modelling and reasoning. For example, research works from Henricken and Indulska (2004), Chen et al. (2003) and Wang et al (2004) all proposed to utilised locational information with ontology modelling technique to provide context aware service in smart space use cases. Alternatively, based on a XML based semantic representation, Hofer et al. (2003) proposed the Hydrogen framework, to provide adaptive information presentation by utilising time, location device and network context.

Interest Profiling

Interest profiling refers to techniques that seeks to capture information user's interest and profiling by either explicitly gathering such information or implicit reasoning. RSS (**R**eally **S**imple **S**yndication) based on user indicating explicit information preference represented in XML syndication format to guide information aggregation and delivery on the operator side. With more implicit approach, recommender systems use rating for items such as movies, news or books to recommend potentially interesting item to users with similar tastes and interest (Resnick & Varian, 1997).

Early application of RSS includes news weblog (Winer, 1997) and site summary (Libby, 1999). More recently, much attention have been placed on using RSS for learning purpose such as support student research project (Cold, 2006) and classroom support (Hendron). As for recommender systems, services such as Amazon's Item-to-Item provides recommendation lists to individual customers by matching each of user's purchased and rated items to similar items (Linden, Smith, & Yourk, 2003).

Knowledge, Skill and Background Profiling

Knowledge, background and skill profiling refer to techniques that capturing user context related to one's domain knowledge, skill sets and background experience (Schiaffino & Amandi, 2009). In knowledge management systems, the skills a user or employee has, the roles he takes within an organization and his performance in these roles are used by managers or project leaders to assign him to the job position that suits him best (Sure, Maedche, & Staab, 2000).

Increasingly, intelligent capabilities utilised these types of user context are being proposed. For example, Draganidis et al. (2006) proposed an ontology based system to support knowledge gap and learning path analysis. With the rise of social computing, social platform such as LinkedIn typically encourage users to specify ones' skill and experiment as part of individual profiles. Such user profiles are then used to facilitate automatic recommendations for connections and professional groups (Skeels & Grudin, 2009).

2.3.4 Conclusive Remarks

Based on the review presented from 2.3.1 to 2.3.4, the context aware techniques reviewed were classified into the following categories: data mining techniques, semantic techniques and profiling techniques. Within each of these categories, specific types of context aware techniques were identified. These are shown in the following table:

Category	Description	Specific Technique Types
Data Mining Techniques	Techniques mainly focus analysing information content.	Text Analysis Link Analysis Information Classification Information Clustering Pattern Analysis
Semantic Techniques	Techniques mainly focus on handling concepts and relationships been concepts	Semantic Representation Resource Description Ontology Modelling Context Inference
Profiling Techniques	Techniques mainly focus on capturing contextual information from information users.	Activity Profiling Physical Sensing Interest Profiling Knowledge, Skill and Background Profiling

Table 2-2: A classification of context aware techniques

It was obvious from this review that, in existing literature about context aware systems, multiple categories of context aware techniques were often applied in the same information system. For example, systems that apply information classification might also apply semantic techniques to generate classification scheme, while physical sensing were often applied in conjunction with ontology modelling in work related to ubiquitous computing.

To this end, the classification presented in Table 2-2 provided a frame work to evaluate context aware techniques applied in a given information system. For this reason, it was used as a system dimension to review selected information systems during the state of the art study. This is presented in Chapter 3.

2.4 Application of Context Aware Systems to Support Knowledge Work

The definition of knowledge worker implies that knowledge work is inseparable from information. As stated by Peter Drucker (1959), they work "*primarily with information*". In today's information age, many knowledge workers reply on performing various computing tasks to conduct their work. While investigating engineering design in the aerospace industry, Campbell (2007, p. 6.11) summarised the four supporting functions that computing tasks provide to aerospace knowledge work. These are *acquisition*, *processing*, *creation* and *dissemination* of information.

In this section, a review is presented to examine how applications from existing context aware systems can be related to these four supporting functions to knowledge work. The applications identified from this review including authoring, semantic lexicon, annotation, search, push. These are discussed in the following from 2.4.1 to 2.4.5. The relation between these applications and the four support functions mention above is then presented in 2.4.6 in the conclusive remarks of this section.

2.4.1 Authoring

"Authoring" here refers to applications that allow new information to be created. As web 2.0 technologies emerge to give individual more opportunity to author information, increasingly huge amount of unstructured information are being created. This has lead to researches about how to ensure information created in increasing diverse setting can be: firstly processed and interpreted by information systems; and secondly deliver to information use who might be interested at such content.

Among these researches, applications had been proposed to encourage information user to create information in underlie format that can be readily processed by information systems. Amaya (Quint & Vatton, 1997) is an early example of such information authoring tool. It allows user to author information in a WYSIWYG (**W**hat **Y**ou **S**ee **I**s **W**hat **Y**ou **G**et) manner. Additionally, it allows information to be created in HTML and XML structure, so that key elements such as text, mathematics and graphics can be annotated during the authoring process.

An noticeable strand of examples are semantic wiki systems that allow user to create online knowledge base with underlying semantic representation, but at the same time offer the same openness as that of the now famous Wikipedia (2012) initiative. Some examples of these semantic wiki include the following: IkeWiki (Schaffert, 2006); FreeBase (Bollacker, Evans, Paritosh, Sturge, & Taylor, 2008); and SweetWiki (Buffa, Gandon, Ereteo, Sander, & Faron, 2008).

Additionally, there are applications that target information authoring in ubiquitous setting. These often involve applying profiling techniques to automatically create annotated information as user embodies multimedia information in heterogeneous environment. For example, M-studio which allowed mobile story creators design, simulate and adjust model narratives (Pan, Kastner, Crow, & Davenport, 2002).

With relation to the four supporting functions of computing tasks to knowledge work, these applications firstly provide the means to create information. Additionally, these applications utilised semantic techniques to ensure that the information created can be easily processed by information systems for further potential applications.

2.4.2 Semantic Lexicon

"Semantic lexicon" refers to applications that aim to create dictionary of words with underlying semantic representation. In additional to allowing information user to look up a given concept and various related concepts, the underlying semantic representations allow information system to process selected segment or the whole collection of concepts contained in the dictionary.

An example of such semantic lexicon is WordNet (Miller, Beckwith, Fellbaum, Gross, & Miller, 1990) which is an early attempt to use taxonomies to construct a large lexical database of English. In this database, "*Nouns, verbs, adjectives and adverbs are grouped into sets of cognitive synonyms (synsets), each expressing a distinct concept*" (Princeton University, 2012). Focused on multiple languages, BabelNet (Navigli & Ponzetto, 2010) utilised automatic approach to link concepts from WordNet with multilingual content on Wikipedia. With a more domain specific purpose, Johnson (1999) created a semantic lexicon tailored for medical specialist.

With relation to the four supporting functions of computing tasks to knowledge work, these applications provide out of the box semantic representation for generic or domain specific vocabulary. These firstly can be used by knowledge worker to acquire information for their work, and secondly can be used for information processing activities such as generating information summarisation and semantic annotation, as described in 2.4.3.

2.4.3 Descriptive Information Generation

"Descriptive information generation" refers to applications that generate descriptive information about given information object. Such descriptive information includes summary, key words or various forms of annotation.

As already discussed in 2.3.1, applications have been developed to apply automatic text analysis techniques to generated information summary and key words. Perhaps one of the most used of such type of application is that of automatic summary of MS Word[1] (Microsoft, 2012) which allow user to generated summary of a document of various length. Online tool such as Wordle (Viegas, Wattenberg, & Feinberg, 2009) allow user to submit section of text to generate so called "word cloud" made up with key words

[1] Discontinued since MS Office 2010

Apart from automatic application mentioned above, the application of semantic techniques to generate descriptive information has been a much researched topic. Applications to automatically or manually generated semantic annotations have been both proposed and developed. Such applications allow annotations of given information object to be generated according certain given semantic representation. The authoring applications described above seek to create such semantic annotations when information is created. In the other hand much focus is on applications to annotate information that is created without underlying semantic representation. For example, Text2Onto (Cimiano & Volker, 2005) is a system that seeks to create ontology by learning from text content as well as human user input. MS LiveLabs Pivot (Microsoft, 2012) allows users to annotate information using taxonomy for future searching and classification.

With relation to the four supporting functions of computing tasks to knowledge work, these applications allow information to be processed for the following purpose: firstly they provide aid for knowledge worker to recognise or understand the processed information; secondly such processed information can be easily utilised by information systems to provide applications such as information search or information push.

2.4.4 Information Search

"Information search" refers to applications that provide information retrieval service for information users. These include typical information search service such as search engines, as well as database applications that allow users to perform search on associated data set. In particular, the review of search applications did not include application based on mature approaches which had already become standard practices, such as text indexation, crawling, and SQL query.

Information search, especially which of online search engines, has been one of the key drivers of the information revolution in the last decade. The search engine Google (Google, 2012) is so popular that the word "google" is often used instead of the word "search". Compare to other application discussed in this section, information search is probably the most researched and developed area for context aware capabilities. In the public space, search engines such as Blekko (Blekko, 2012) encourage users to provide information to indicate trustfulness of individual information source. While the search engines Yippy (Yippy, 2012) applies information clustering and classification techniques to allow user to navigate information from different perspectives.

The information search applications described above were mostly based on data mining techniques. In additional to these, much attention had been paid to application of semantic techniques to facilitate so called "semantic search". Semantic search seek to improve on traditional search methods by exploiting the semantic metadata (Uren, et al., 2007). For example, SemSearch (Lei, Uren, & Motta, 2006) is a search that based on knowledge bases in RDF format which perform search terms expansion to translate keyword into formal semantic query. Departing from the typical keyword based search, the mSpace (Wilson, Russel, & Smith, 47-49) search engine introduces interactive columns driven by ontology model. Each of these columns represents different information faceted and allow for additional navigation flexibility on the underlying dataset.

The popularisation of smart mobile devise search has lead to much effort to offer personalised information search applications. Applications such as Aloqa (Motorola, 2012) apply profiling techniques to allow user to search for venues or events that are nearby or match with personal preference. Increasingly, social networking applications such as Facebook (Facebook, 2012) allow users to search for personal contact that close to their location.

With relation to the four supporting functions of computing tasks to knowledge work, these applications allow knowledge work to acquire information by specifying their information need.

2.4.5 Information Push

"Information push" refers to applications that seek to deliver relevant information to users via an automatic process. From a technical perspective, these applications rely on profiling techniques to inference the short term or long term information preference of the information users, and then gather and deliver information that match such preference.

Early example of such application includes systems that such as AMS that disseminating activity map information to users carrying mobile devise (Schilit, Adams, & Want, 1994). The remembrance agent (Rhodes & Maes, 2000) profile user's computing activity and provide potentially useful information during information authoring process. From a commercial point of view, probably the most successful form of information push application is that of recommender systems. Online retailer such as Amazon (Amazon, 2012) provided purchase recommendation based on user's personal back as well as purchase history. One can argue that the increasingly standard feature of search suggestion can also be classified as an application of information push. This type of search suggestion functionality, as implemented by typical search engine such as Google (Google, 2012) and Bing (Microsoft, 2012) automatically deliver potentially useful search term as users type in their search terms.

With relation to the four supporting functions of computing tasks to knowledge work, these applications firstly allow automatic dissemination of information. Secondly, information push can deliver information at the right point during work process to provide assistance to information authoring – as in the case of remembrance agent, and information acquiring – as in the case of search terms suggestion.

2.4.6 Conclusive Remarks

From 2.4.1 to 2.4.6, five types of applications provided by existing context aware systems are discussed. Each type of applications realise one or more of the four supporting functions to knowledge work. An overview is provided in Table 2-3 below:

	Acquisition	Processing	Creation	Dissemination
Authoring		✓	✓	
Semantic Lexicon	✓	✓		
Descriptive Information Generation		✓		
Information Search	✓			
Information Push	✓		✓	✓

Table 2-3: Supporting functions to knowledge work vs. Applications of context aware systems

The identification of these five types of applications provided by context aware systems, as well as the mapping between each applications to key supporting functions to knowledge work, helped to establish understanding on how context aware system can support knowledge work. These five application types were used in the state of the art review to review existing context aware systems. This will be presented in Chapter 3.

2.5 Research Issues Related to Industrial Application of Context Aware Systems

In this section, research issues related to industrial application of context aware systems are reviewed. As mentioned in Section 2.3, distinct research and development fields have developed from each of the three categories of context aware techniques. For this reason, the review presented in this section was structured by reviewing issues related to each category of technique, as seen in subsections 2.5.1 to 2.5.3. Conclusive remarks are then presented in subsection 2.5.4.

2.5.1 Context Aware Systems Applying Data Mining Techniques

Harding et al. (2006) conducted a review on the use of data mining in manufacturing; they concluded that although there were several manufacturing enterprises that have benefited from data-mining techniques, there was much room for further adoption. Specifically, areas such as manufacturing operations, fault detection, design engineering and decision support systems have gained attention of the research community. On the other hand, areas such as maintenance, in-service, layout design, and resource planning and shop floor control require more attention and further exploration. This study particularly points out it is rather surprising that the aerospace industry, although routinely collect huge quantities of data, does not have much increase in the adoption of data mining application.

In term of future direction of application in the enterprise domain, it has been pointed out that one of the area that need further exploration is how to develop generic systems that can be integrated with existing systems (Harding, Shahbaz, Srinvas, & Kusiak, 2006; Kusiak, 2007). Related to this, data mining applications need to be able to process not only information in structured data bases system, but also those created and stored in unstructured form (Kusiak, 2007; Goh, Giess, McMahon, & Liu, 2009) in traditional ICT infrastructure (Xie, Culley, & Weber, 2011a). However, current approaches to address unstructured information often rely on manual methods to annotate information which is often inefficient and expensive (Goh, Giess, McMahon, & Liu, 2009).

It has also been suggested that more work is needed to be done to address cross-domain application. In a survey that focus on the use of summarisation in medical domain, Afantenos et al. (2005) emphasised that data mining technology that developed in particular domain need to be able to ported to new domain with reusable and trainable component and resources.

2.5.2 Context Aware System Applying Semantic Techniques

In the public domain, semantic techniques are starting to be applied in highly visible information services, such as Wikipedia and major search engines. For example, the search engine Bing can return information content with author, related content, highlighted section and popular links for many of the Wikipedia pages.

However, despite strong push from consortium such as W3C via initiative such as semantic web the application of semantic techniques in the enterprise sector is few and far between. Compare to that of web 2.0 technologies, which are relatively wider adopted in the enterprise in relative short time frame, the adoption of semantic techniques has been slow despite accumulating large body of literature on development and deployment topics (Zambonini, 2006).

The reason seems to be multifaceted: From business and user perspective, it is not yet clear enough to typical enterprise users exactly what problems such technologies solve and what benefits these might bring (Beltran-Jaunsaras & Carbonell-Perez, 2010), and the use of semantic techniques inherently depends on people to contribute their time to facilitate key element such as the population or creation of semantic representations (Ankolekar, Krotzsch, Tran, & Vrandecic, 2007). From a technological perspective, the underlying technology require a high level of complexity (Beltran-Jaunsaras & Carbonell-Perez, 2010), and essential facilitation tools are often gear toward the usage of knowledge engineers rather than business users (Xie, Culley, & Weber, 2011). From an organisational perspective, the nature of closed domains in the enterprise space in many traditional sections inherently cause difficulties to achieve inter-changeable context models which semantic techniques rely on (Ankolekar, Krotzsch, Tran, & Vrandecic, 2007).

Despite it is slow uptake, there is much evidence from existing research that the drive to adopt semantic techniques into enterprise space is still strong. W3C maintain a list (Baker, Noy, Swick, & Herman, 2012) of case studies of deployment of semantic techniques in production environment of organisations. In this collection of use cases, the most documented usages (total of 45 cases, and usages are not mutually exclusive) are data integration (30 cases), improve search (22 cases), information portal (16 cases), content discovery (12 cases) and semantic annotation (11 cases) However, many of these cases studies are conducted in setting with particular stake to be open and transparent about information usage, such as public institution (17 case) and government initiative (9 cases). To the contrary, in traditional enterprise the number of case are much lower - example of these are automotive (3 case), energy (3 cases) and oil & gas (2 cases)

In a separate study, the Value-IT project co-funded by the EU looking into the potential scenarios of application of semantic techniques in enterprise for a wide range of industries, identifying challenges, applications need, market potential for each sector (Value-IT, 2010). For example, for the manufacturing section, this study highlighted that semantic techniques that support conceptual activates − namely for applications that exhibit interactive behaviour, mapping of terms and phases as well as classification, as well as knowledge sharing , are among the most needed applications.

2.5.3 Context Aware Systems Applying Profiling Techniques

There is little existing literature one how systems applying user profiling techniques are being adopted in the enterprise domain. Schiaffino and Amandi (2009) pointed out the rise of interest of user profiling in particular in the area of knowledge management, for purpose such as matching employee's skill with position as mentioned in 2.3.3 above. Additionally, building customer profiles are important for customer relationship management (Bose & Sugumaran, 2003).

One of the key issues for current user profiling techniques is the transparency to the daily information user. Godoy & Amandi (Godoy & Amandi, 2005) pointed out that user profile that generated by technique such as information agents often act as "black box" to most users. And the representation of user interest is often difficult for non-expert users to understand. This may result in a loss of trustworthiness (Herlocker, Konstan, & Riedl, 2000)in the enterprise domain where the perceived value of information is often influenced by the level trustworthiness (Ko, Kirsch, & King, 2005). This transparency issue is likely to become a barrier for industrial application.

2.5.4 Conclusive Remarks

From subsections 2.5.1 to 2.5.3, literatures that address current status of industrial application of context aware systems applying different techniques are reviewed. Specific research issues are highlighted. These highlighted issues are summarised in Table 2-4 below:

ID	Research Issue	Related Category of Context Aware Technique
I1	Integration with existing systems	Data mining techniques
I2	Effort to capture context	Data mining techniques Semantic techniques
I3	Demonstration of benefit	Semantic techniques
I4	Transparency to users	Semantic techniques Profiling techniques
I5	Reusability of captured context	Data mining techniques Semantic techniques

Table 2-4: Research issues related to industrial application of context aware systems

As shown in Table 2-4, an ID code is assigned to each research issue. This is for the simplicity of referencing in Chapter 5. Three of the research issues in this table are summarisation of research issues for different categories of techniques that share similar aspect; these are discussed in the following:

- The research issue "effort to capture context" is the summarisation of 1) applying data mining techniques to address unstructured information; and 2) the dependency on capturing semantic context via manual facilitation. Because both issues are related to high demand of manual effort to capture information context.

- The research issue "transparency to users" is the summarisation of 1) the lack of facilitation tool applicable for business users to capture semantic context; and 2) a the lack of transparency from profiling techniques. Because both issues are related to users not being able to understand and act upon what context is captured.

- The research issue "reusability of captured context" is the summarisation of 1) the need to port data mining techniques developed in one domain to another; and 2) the difficulty to share semantic model among different domains in enterprise. Because both issues are related to reusing captured context in other domains.

2.6 Summary

Within the literature review, previous research works from existing literature were reviewed to provide insight that support subsequent research activities in this project. In Section 2.1, a classification of context is presented to summarise the key context types and context elements addressed from previous research works. The three types of context that are identified are: context from information consent, semantic context and user context.

An overview on context aware system is provided in Section 2.2 to summarise the key capabilities of context aware system as well as core process required to achieve this capabilities. Context aware techniques applied in existing research and developments are then discussed in Section 2.3. A classification of three categories is presented, including data mining techniques, semantic techniques and profiling techniques. These methods and techniques originate from a wide range of research fields, but all contribute to the capturing and utilisation of contextual information.

In Section 2.4, five types of applications provided by existing context aware systems are discussed. Each application type is related to one or more of the four supporting functions that provide support to knowledge work. The classification of context aware techniques, as well as the application types provided by context ware system, was used as key system dimension to review a wider selection of context aware systems than those covered in the literature review. This is presented in Chapter 3.

Key research issues to do with industrial application of context aware systems are reviewed in Section 2.5. As a result, a list of research issues is provided. This list of research issues, alongside with research outputs from the state of the art review and industrial case study, contributed to the scoping of further investigation in the experiment phase, as described in Chapter 5.

3 State of the Art - Systems Review

This chapter gives an overall summarisation on systems that have been reviewed that are relevant to this research project. The key objective of this system review is to identify potential gaps with relation to the research and development of context aware systems in academia, commercial, the aerospace industrial setting. These identified gaps are then further analysed and explored in Chapter 5 in conjunction with outputs from other research activities in the investigation phase.

Within this chapter, the background of this state of the art review is presented in 3.1, followed by a summary of the review methods in 3.2. The overall results of this review are presented in 3.3. The detailed studies are then presented in 3.4.

3.1 Background to the Review

In the Chapter 2, a literature review is presented. A key outcome of this reviewed is a classification of three categories of context aware techniques. These are techniques that had been applied in previous research works. In the state of the art system review, information systems that apply these context aware techniques are reviewed. Additionally, five types of applications from context aware systems that support knowledge work are discussed.

It was considered that in this space the state of the art would reside both in the academic literature as dealt with in Chapter 2 and within systems that had been developed, tested or deployed. The systems evaluated originated from different setting, some are results of research projects from academic, commercial or industrial backgrounds, while other have been available for use in the public domain, also included were systems that were used in the aerospace industrial environment.

It is worth pointing out that this state of the art system review was performed in the early stage of the study (i.e. from year 1 to year 3 of the project). Since then, rapid progress had been made in the field of information technology. In particular, semantic techniques and profiling techniques were commonly applied in mainstream commercial systems (i.e. Google, LinkedIn, Microsoft Bing) by the latter part of this project. Review for these systems were added to reflect such technological progress. However, this state of art review does not claim to systematically reflect the latest stage of context aware system development at the time this thesis was written.

3.2 Summary of Review Methods

The main method of this review is to provide a comprehensive review on information systems that can be considered as context aware systems. In particular, information systems that apply context aware techniques to both capture and utilise context were considered. The selection criteria of systems included in the review is discussed in 3.2.1. The key evaluation dimensions used in the review are discussed in 3.2.2. The review process is then discussed in 3.2.3.

3.2.1 Choice of Systems

The definition of context aware systems was considered when deciding whether a system should be included in the review. As mention in Chapter 1, context aware systems are information systems "*that are able to adapt their operations to current context without explicit user intervention*". This definition implies that such system shall be able to somehow react to "*current context*" by capturing and utilise such context. Based on this, systems include in this review are those that both capture and utilise context information to fulfil information tasks that are otherwise difficult or expensive for manual effort.

Semantic modelling tools such Protégé (Stanford University, 2013) were not included for the reason that they generally do not provide applications that utilise the captured context. Information visualisation tools such as Compendium were not reviewed for the reason that they don't implement any specific techniques to capture such context other than using traditional manual efforts.

Techniques such as relational databases and SQL were also not included in this review since they were considered to be mature technology and were already widely adopted. On the other hand, there were systems that use semantic techniques based on these mature techniques but also demonstrate capabilities beyond such standard approaches. These systems are included in the review. The detailed list of system featured in the review is given in Appendix A.

3.2.2 System Review Dimensions

In this state of the art review, the selected information systems were reviewed from four key system dimensions. These are:

- *Automation level*: The level of automation that is applied by a system to capture context.
- *System application*: The applications a system provide to its users by utilising captured context.
- *Context aware technique*: The context aware techniques applied by a system to capture, model, and reason and utilise context.
- *System origin*: The research or development nature of the setting under which a system is developed.

The rationale for applying these four system dimensions came from both the research aim of this project, and the literature review presented in Chapter 2. The research aim was to "*investigate the application of context aware systems to capture and utilise context to support knowledge work in the aerospace industry*". It was therefore critical to understand how the context capturing and context utilisation process were performed in existing context aware systems.

For context capturing, among existing literature, context capturing approaches ranged from that of fully automatic to fully manual. Although automatic features are considered to be vital to ease human effort, manual effort still plays an important role to provide human intelligence. In order to understand how this is addressed in previous systems, context capturing approach applied in previous works were classified into three types of approaches: automatic capturing, manual capturing and semi-automatic capturing.

For context utilisation, this review focused how context aware systems provide applications that support knowledge work. As already discussed in Chapter 2, five types of information applications that support knowledge work were identified in the literature review, namely that of authoring, semantic lexicon, descriptive information generation, information search and information push. These applications type were applied in the state of the art review to review selected system from the "system application" dimension. Each application type was used as a review criterion in this dimension. Additionally, an "other" criterion was introduced to include applications that didn't fit into the five aforementioned application types.

In the "context aware techniques" dimension, the classification of context aware techniques presented in Chapter 2 was applied. Each of the three context aware technique categories, namely that of data mining techniques, semantic techniques and profiling techniques, correspond to each of the three criteria, was used as a review criterion in this dimension. Additionally, each specific type of techniques was listed as specific feature under the corresponding criterion.

Finally, the "system origin" dimension allowed the selected systems to be analysed from different research and development setting. By cross correlating analysis results of this dimension with that of other dimensions, potential gaps of research and development of context aware systems can be identified with relation to the aerospace industry. Two types of settings were introduced, research setting for system developed with research purpose, this include academic research, commercial research and aerospace research; Commercial setting for system developed with purpose to be used for commercial purpose, this include public usage and aerospace usage. In particular, the "aerospace usage" criterion was introduced to analysis the research and development status of context aware systems in the aerospace industry.

Table 3-1 to Table 3-4 provide overall information to each key dimension and the corresponding list of criteria:

Key Dimensions	Dimension Descriptions
Context Capturing Automation Level	The level of automation that is applied by a system to capture context. A system can adopt an approach based on manual effort, automatic methods, or a combination of both. A system will only be classified in one of the following three criteria
Criteria	Criteria Descriptions
Automatic	Indicate a system mainly applies automatic methods to capture contextual information
Manual	Indicate a system mainly applies manual methods to capture contextual information

Semi-Automatic	Indicate a system applies both automatic and manual methods to capture contextual information

Table 3-1: Automation level of context capturing

Key Dimensions	Dimension Descriptions
System Applications	The application which an information system provide to its users. The application types were identified in the literature review from applications provided by existing context aware systems.
Criteria	Criteria Description
Authoring	Indicate a system provides the application for users to create information.
Semantic Lexicon	Indicate a system provide application that specifically aims to create semantic representation of either generic or specific vocabularies, and also provide service for such semantic representation to be utilised
Descriptive Information Generation	Indicate a system provides the application for descriptive information to be created and associate to certain information content.
Search	Indicate a system provides the application for users to search for information
Push	Indicate a system provides the application for information to be pushed to users
Other	Indicate a system provides applications for user to perform information tasks that don't belong to the four aforementioned application types. For the systems reviewed, this include: Smart Location, Adaptive Presentation, Intelligent Answers, Design Pattern Identification, Behaviour Prediction, Translation, Recommendation and Digitalisation.

Table 3-2: System applications

Key Dimensions	Dimension Descriptions	
Context Aware Techniques	The category of context aware techniques used by a system to capture and utilise context. This can be one of the four categories of context aware techniques identified in the literate review. Specific Features are provided to outline specific context aware techniques under each category. A system could apply multiple specific features from multiple categories.	
Criteria	Criteria Descriptions	Specific Feature
Data Mining Techniques	Indicate a system applies data mining approach to analyse information content, in order to capture and utilise context.	- Text Analysis - Linkage Analysis - Information Classification - Information Clustering - Pattern Analysis

Semantic Techniques	Indicate a system applies semantic techniques to represent both individual concepts and their inter-relationships. Such semantic representations then allow for utilisation of contextual information on a semantic level.	- Simplistic Semantic Representation - Resource Description - Ontology Modelling - Context Inference
Profiling Techniques	Indicate a system applies techniques that attempt to capture context of information users. Such profiles are then used to facilitate targeted applications.	- Activity Profiling - Physical Sensing - Interest Profiling - Knowledge, Background and Skill Profiling

Table 3-3: Context aware techniques

Key Dimensions		Dimension Descriptions
System Origin		This is to indicate in the setting a system is researched, developed, being available and adopted. A system can be assigned to only one setting. The author takes the view that systems that are available in commercial setting are of higher maturity than those originated in research setting.
Criteria		Criteria Description
Research	Academic Research	Indicate a system is developed as a result from a research project carried out by academia institution.
	Commercial Research	Indicate a system is developed as a result from a research project carried out by commercial organisation.
	Aerospace Research	Indicate a system is developed as a result from a research project carried out by organisation with related to the aerospace industry.
Commercial	Public Domain Usage	Indicate a system is available in the public domain in various form e.g. commercial product, freeware, freemium, open source, etc.
	Aerospace Usage	Indicate a system is evidently used in the aerospace industry in operational setting.

Table 3-4: System origins

3.2.3 Systems Review Process

A total of 73 information systems were evaluated using the four system dimensions outlined in 3.2.2: context capturing automation level, applications types, usage of context aware techniques and system origin.

The review of the selected systems were performed in the following manners: 1) For systems that were available for direct access via online download or web-based evaluation, evaluative usage were perform to understand how such systems corresponded to the four system review dimensions. 2) For systems that were not available directly – these mainly included academic prototypes, review were performed by reviewing either research papers directly associated such systems or research papers providing state of the art review that included a given system in question.

During the review, firstly the systems were mapped on each of these four dimensions. This was to provide an overview on how existing research and development were distributed alongside individual aspect. These yielded four "system distribution" tables. They are presented in 3.3 with associated discussion.

Secondly, the "system distribution" on context capturing automation level, application types and usage of context aware techniques were each cross correlated with that of systems origin. This was to reveal specific gaps on each system dimensions with regard to research and development origin of existing systems. These are presented from 3.4.1 to 3.4.4.

Additionally, many systems featured various combinations of context aware techniques and applications. These combinations are also cross correlated with the system origin dimensions and presented in 3.4.4 and 3.4.5.

3.3 Overall Results

Detailed evaluation data for this system review and the list of systems are provided in Appendix A. The following tables provide overall results in term of how the systems distribute on each system dimension:

Distribution of Automation Level	Automatic	Manual	Semi-Automatic
Sum	33	18	22

Table 3-5: Overall systems distribution - automation level

Distribution of Context Aware Techniques	Data Mining Techniques	Semantic Techniques	Profiling Techniques
Sum	43	42	27

Table 3-6: Overall systems distribution - context aware techniques

Distribution of System Application	Authoring	Semantic Lexicon	Descriptive Information Generation	Information Search	Information Push	Other
Sum	5	5	33	38	17	7

Table 3-7: Overall systems distribution - system applications

Distribution of System Origin	Academic Research	Commercial Research	Aerospace Research	Public Domain Usage	Aerospace Usage
Sum	31	10	9	21	2

Table 3-8: Overall systems distribution - system origin

In terms of automation level, the most applied approach to capture context was automatic approach (33 systems), while the least applied approach was manual approach (18 systems). Detailed analysis on this dimension is presented in sub-section 3.4.1.

Judged from the overall distribution of systems from the context aware techniques dimension, there is a fair amount of interest in applying techniques from each category, however there are comparatively more research and development conducted using the data mining and semantic techniques. Detailed analysis on this dimension is presented in sub-section 3.4.2

From an application perspective, it was obvious from this review that by far the most targeted applications were descriptive information generation and information search. Although there were only a small number of system featuring "authoring" and "semantic lexicon", the semantic information they provided were used by many system using semantic techniques to facilitate utilisation of semantic context. Further analysis on this dimension is presented in 3.4.3

In term of System Origin, there was an interesting distribution with significant amount of research conducted in the academic environment (31 systems), and a certain amount in the commercial (10 systems) or aerospace research setting (9 systems). Many systems were also available in the public domain (21 out of 73 surveyed). However, one 2 systems were evidently used in the aerospace industry in operational setting.

Key Finding 1: Despite significant amount of systems coming from research background and also from public domain, very few contexts aware systems were used in aerospace in operational setting[2].

3.4 Detailed Results

Based on the overall results, a series of comparison matrices were constructed to visualise the distribution of the reviewed systems. From sub-sections 3.4.1 to 3.4.3, detailed analysis results are presented to visualise how the systems of different origins distributed within the *automation level of context capturing*, *context aware technique* and *system application* dimensions. Sub-sections 3.4.4 and 3.4.5 then present how the systems of different origins featured different combination of context aware techniques and system applications. Finally, additional finding is present in 3.4.6

3.4.1 Context Capturing Automation Level

When cross correlated with the *system origin* dimension, as seen in Table 3-9, automatic approach was the most applied approach in every setting apart from "Aerospace Research". From this table, automatic approach was the most applied approach to capture context.

[2] The two systems that identified to be in operation use in the aerospace are:

1. MS Office Word - Word processor that provided automatic summarisation function before MS Office 2010 versions.
2. Vivisimo Velocity - A enterprise search engine which provided information search application that can be enhanced by by semantic representations. This enterprise search engine was in the process of becoming the official enterprise search tool in Airbus at the time of study.

Automation Level vs. System Origin	Research			Commercial	
	Academic Research	Commercial Research	Aerospace Research	Public Domain Usage	Aerospace Usage
Automatic	13	6	3	10	1
Manual	9	2	2	5	0
Semi-Automatic	9	2	4	6	1

Table 3-9: Detailed results - context capturing automation level by system origin

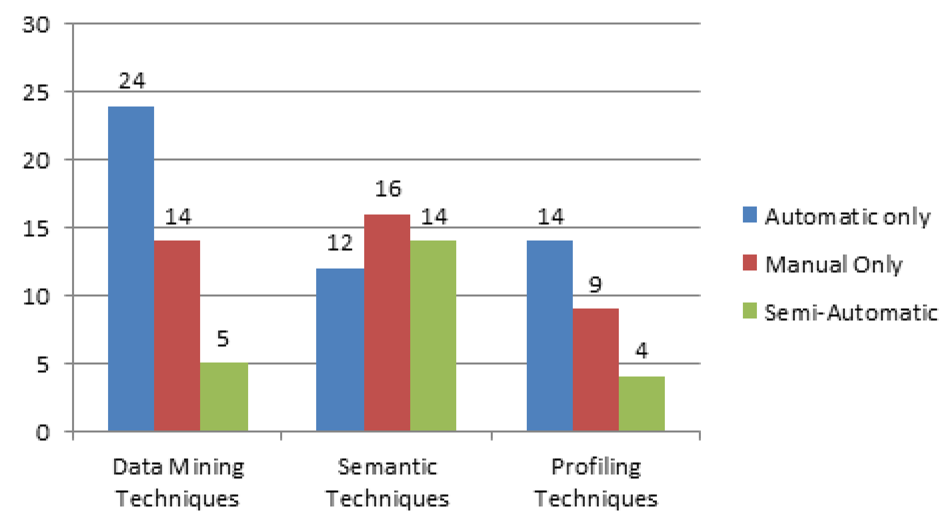


Figure 3-1: Context capturing automation level breakdown by context aware techniques

Additionally, more details were revealed when the *automation level* dimension was cross correlated with the *context aware techniques* dimension. It was observed that although automatic approach was still the most applied in systems that applied data mining techniques and profiling techniques. In systems that applied semantic techniques, manual and semi-automatic approaches were more applied.

Key Finding 2: While automatic approaches gathered more interest, the manual and semi-automatic approaches were more applied when semantic techniques were applied in a system. The key issues here is the challenge to balance between the labour cost of context capturing via a manual approach, and the accuracy of capturing offer by today's technology.

3.4.2 Context Aware Technique

The distribution of systems with different context aware techniques against different system origin is shown in Table 3-10. This was then then further analysed by grouping number of systems under research and commercial system origin categories, as shown in Figure 3-2.

System Origin vs. Context Aware Techniques		Data Mining Techniques	Semantic Techniques	Profiling Techniques
Research	Academic Research	17	21	11
	Commercial	3	5	4

	Research			
	Aerospace Research	7	6	4
Commercial	Public Domain Usage	14	9	8
	Aerospace Usage	2	1	0

Table 3-10: Detailed results - context aware techniques by system origin

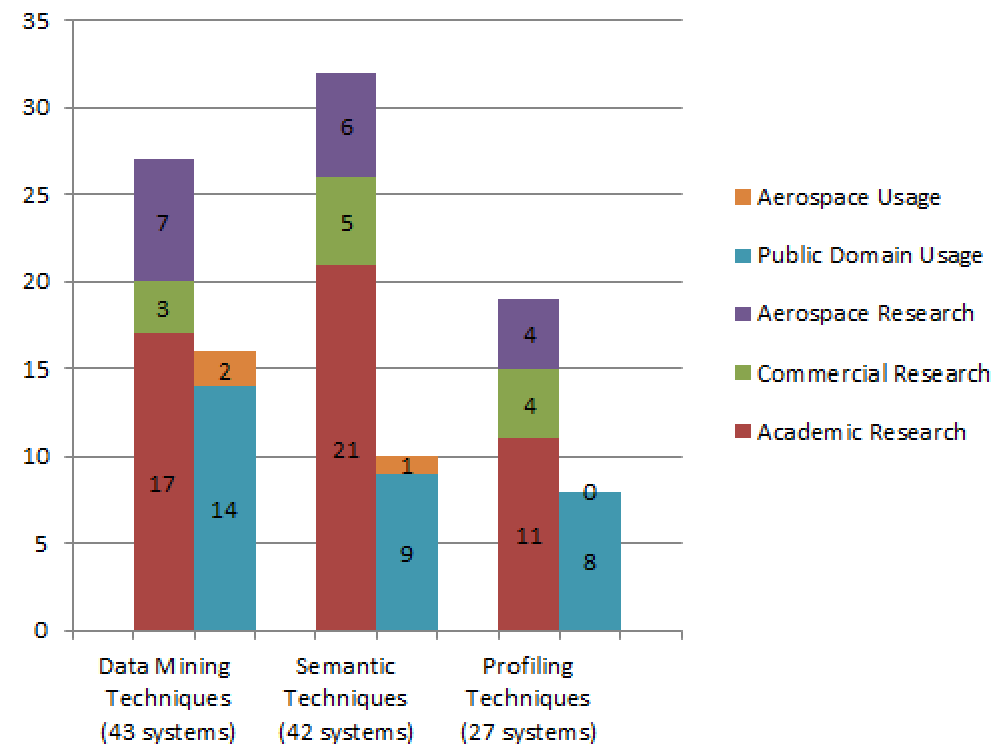


Figure 3-2: Context aware techniques: research vs. commercial setting

Among systems that applied data mining techniques, 37.2 %(16 out of 43) of these systems were developed in commercial setting. The corresponding figure for systems that applied semantic techniques was 23.8% (10 out 42), and 29.6 %(10 out 27) for systems that applied profiling techniques.

Key finding 3: Among the three categories of context aware techniques, data mining techniques were most applied in systems for commercial purpose.

Key finding 4: Among the three categories of context aware techniques, semantic techniques were least applied in systems for commercial purpose.

3.4.3 System Application

Within the systems reviewed, as seen in Table 3-11, there is no attempt to provide authoring or semantic lexicon as an application within the aerospace industry in both research and commercial setting.

System Origin vs. Application Types	Authoring	Semantic Lexicon	Descriptive Information Generation	Search	Push	Other

Research	Academic Research	1	3	13	12	6	5
	Commercial Research	2	0	5	6	1	0
	Aerospace Research	0	0	5	6	2	1
Commercial	Public Domain Usage	2	2	8	13	7	1
	Aerospace Usage	0	0	2	1	1	0

Table 3-11: Detailed results- system application by system origin

As already mentioned previously in 3.3, although the number of systems that offered authoring and semantic lexicon application were not high, many systems built on the semantic representations resulted from these authoring and semantic lexicon application.

This had not been the case in the aerospace industry, although there are a number of industrial based systems applying semantic techniques to create semantic representation of aerospace context (Dormon, Lakshmanan, & Nuzzo, 2007; Redon, Larsson, Leblond, & Longueville, 2007; Verhagen, et al., 2012), they were not integrated with other research or commercial project. There was no evidence that further system development reusing these semantic representations.

Key finding 5: This indicated a clear gap to investigate possible opportunities to apply semantic representation to capture aerospace context in an integrated and open manner.

3.4.4 Combination of Context Aware Techniques

The system distribution in terms of combination of system techniques is shown in Table 3-12. Table 3-13 provides further breakdown of this system distribution based on the system origin dimension. Furthermore, system distribution in Table 3-13 is visualised in Figure 3-3 to show the comparison between research and commercial settings.

Combination of Context Aware Techniques	One	Two	Three
Sum	38	31	4

Table 3-12: Combination of context aware techniques - overall distribution

Combination of Techniques by System Origin		One	Two	Three
Research	Academic Research	14	16	1
	Commercial Research	8	2	0
	Aerospace Research	2	6	1

Commercial	Public Domain Usage	13	6	2
	Aerospace Usage	1	1	0

Table 3-13: Combination of techniques by system origin

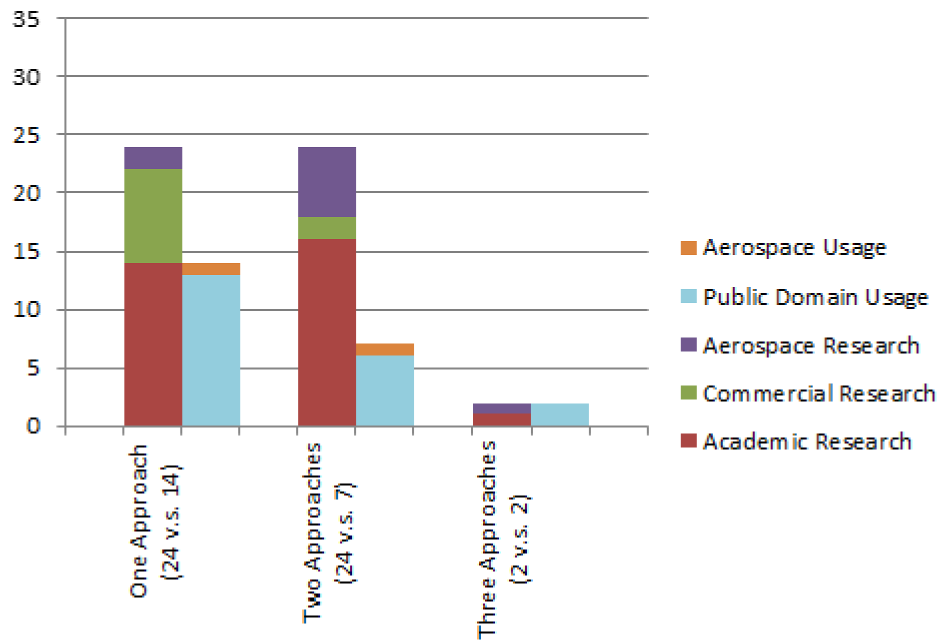


Figure 3-3: Combination of techniques – research vs. commercial setting

It is evident from Table 3-12 that the vast majority (69 out 73) of reviewed systems implemented techniques from no more than two categories of context aware techniques. Additionally, although only 4 systems applied techniques from all three categories, two of these systems were used for commercial purpose.

Key Finding 6: It is revealed that although not many systems applied more than two approaches, these systems that are most likely to be used commercially.

3.4.5 Combination of System Applications

The system distribution in terms of combination of system applications is shown in Table 3-14. Table 3-15 provides further breakdown of this system distribution based on the system origin dimension. Furthermore, system distribution in Table 3-13 is visualised in Figure 3-4 to show the comparison of amount of systems between research and commercial settings.

Combination Of Application Types	One	Two	Three
Sum	44	26	3

Table 3-14: Combination of system application - overall distribution

Combination of Applications Types by System Origin	One	Two	Three

Research	Academic Research	22	9	0
	Commercial Research	6	4	0
	Aerospace Research	4	5	0
Commercial	Public Domain Usage	11	8	2
	Industrial Usage	1	0	1

Table 3-15: Combination of system applications by system origin

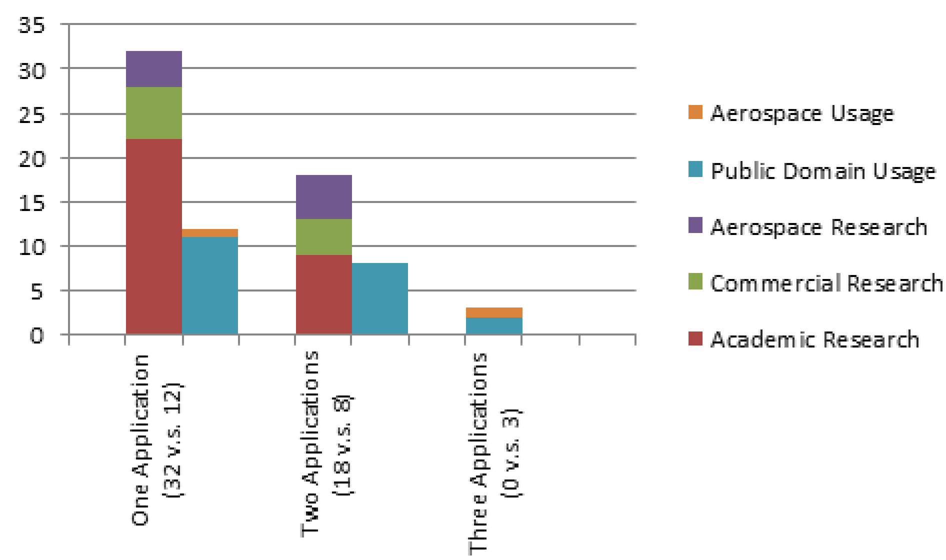


Figure 3-4: Combination of applications – research vs. commercial

It is evident from Table 3-14 that the vast majority (70 out 73) of reviewed systems provided no more than two types of system applications. Furthermore, no reviewed system provided more than three types of system applications. Although only 3 systems provided three types of applications, they were all developed for commercial purpose.

Key finding 7: Although not many systems attempt to provide more than three types of applications, they were all used commercially.

3.4.6 Additional Findings

In additional to the findings listed in previous sessions, the following key findings were also apparent:

Key finding 8: Among the 9 systems originated from aerospace research projects, none has attempted to perform in-depth capturing of domain context. Redon et al. (2007), Malin et al. (2010), and Verhagen et al. (2012) had conducted work related to domain specific engineering work, however these were only limited to small to medium sample size.

Key Finding 9: Among the 9 systems originated from aerospace research projects, none has investigate how the proposed system might integrate to existing engineering practices. All these research projects had focus on technical demonstration of the proposed application on context aware techniques in a laboratory setting, with very litter evidence on how such approaches can actually deliver benefit to real-life engineering problems.

3.5 Summary

As presented in sub-sections 3.3 and 3.4, 9 key findings were identified from the results analysis in the State of the Art review. The key findings helped to point towards some promising research gaps related to context aware systems. These gaps are summarised and listed in Table 3-16.

Overall in the aerospace industry, as indicated in **key findings 1** there were very few existing systems that applied techniques to capture and utilise context in an operational setting. This was despite continuous attempts in the industry to conduct research on this subject, as pointed out in **key finding 9**. This points to a gap in existing research to explore the application of context aware systems in operational setting in the aerospace (**G5**).

As indicated by **key findings 3 and 4**, comparing to data mining, semantic techniques were much less applied in commercial setting. Additionally, despite several previous researches to apply semantic techniques in the aerospace, there was no evident to reuse of results from these researches. This points to a potential gap to investigate the application of semantic techniques in the aerospace industry. This gap was further highlighted by **key findings 5** to capture aerospace context in an integrated and open manner (**G1**).

Related to the application of semantic techniques, **key finding 2** revealed that reliance on manual and semi-automatic approach to capture context in the form of semantic representations. This was also highlighted in among the research issues discussed in 2.5.2. Based on this, a potential research gap is to investigate effective approaches to capture semantic context (**G2**).

Key findings 6 and 7 pointed to evidence that systems applied techniques from more than 2 context aware techniques and feature more than 2 applications were more likely to be applied in commercial setting. However there are very few systems featured in this review satisfy these conditions. This points to another potential gap to investigate the systematic combination of context aware techniques and systems applications (**G3**).

Furthermore, there is a lack of existing research in the aerospace to perform in-depth capturing of domain context, as indicated by **key finding 8**. This points to a gap to investigate how context can be captured with specific engineering domain (**G4**).

ID	Description	Related Key Finding
G1	Application of semantic techniques to capture aerospace context in an integrated and open manner	2
G2	Effective approaches to capture semantic context	3,4,5
G3	Systematic combination of context aware techniques and system applications	6,7
G4	In-depth context capturing of specific engineering domain.	8
G5	Demonstration of proposed benefits of context aware systems in operational setting.	1,9

Table 3-16: Research gaps of application of context aware systems in the aerospace industry

The gaps identified from this system review, combining with research issues related to industrial applications of context aware systems that are listed in Chapter 2, and case studies of industrial practices as discussed in Chapter 4, contributed to the scoping of further investigation in the experiment phase, as described in Chapter 5.

4 Industrial Practices to Capture and Reuse Engineering Experience in the Aerospace

During the investigation phase, investigation oriented activities were undertaken to understand key aspects of context aware systems, existing state of the art research and development of such systems, and industrial practices of knowledge work in the aerospace. The first two of these elements were addressed in the literature review and the state of the art review, as described in Chapters 2 and 3 respectively. The third element of industrial practices was addressed by industrial case studies, as presented in this chapter.

In particular, the industrial case studies featured aerospace knowledge works that focus on capturing and reuse of engineering experience. Two Airbus case studies are presented here: the first case study is about the reuse of previous repair experience to facilitate in-service support, and the second case study about the reuse of lessons-learnt to inform design review. Resulted from these two case studies, a list of context requirements was identified for an ideal context aware system to support knowledge work in aerospace. These requirements highlighted contextual information required for capturing and reusing engineering experience in the aerospace.

In the following sections, the rationale and purpose of performing these two industrial case studies are presented in Section 4.1. The methods taken to conduct the case studies are discussed in Section 4.2. In Sections 4.3 and 4.4, the two case studies are presented in detail. A discussion is then presented in Section 4.5 to consider the difference between the two studied practices and identify common aspects. Finally, a list context requirement are summarised in Section 4.6.

4.1 Rationale and Purpose of Industrial Case Studies

In this section, the rationales for the selection of industrial practices for case studies are presented in subsection 4.1.1. The purpose of the industrial studies is discussed in subsection 4.1.2.

4.1.1 Rationale of Industrial Practices Selection

As already mentioned in Section 1.1, the average in-service life span is about 40 years. Adding to this is the typical development phase of a new aircraft model which requires between 10-15 years. During such long design and product lifecycles, knowledge about the design and service of any individual aircraft need to be maintained. However, the long timespan involved to maintain such knowledge post natural challenges to the retention of engineering expertise, for example:

- *How to make sure repairs performed today on an aircraft will be considered when new repair on the same location of same aircraft is required in30 years' time?*

- *How to make sure previous experience from engineering design can be considered when new aircraft model is developed in two decades' time?*

The types of engineering experience mentioned above − repair experience and design experience − are typical knowledge that requires long term capturing and accumulation for future generation of engineers to learn and reuse. Meanwhile, the potential long time passage between capturing and reusing of these engineering experience means that face to face transfer between engineers is often impractical.

In Airbus, industrial practices are in place to capture such engineering experience in the form of digital information for long term usage. Since context is critical for such digital information to be understood (Alavi & Leidner, 2001), these industrial practices were considered to be promising candidates that can be benefited from the application of context aware systems. It was based on this rationale that industrial practices to capture and reuse these two types of engineering experience were studied during the case study activity.

4.1.2 Purpose of Industrial Case Studies

The purpose was to understand how application of context aware systems might support these industrial practices. The focus of the case studies was not on studying or reviewing documents that capture lessons-learnt or repair cases. Instead, the focus was to understand what contextual information were required in the creation, organisation and use of such information. Furthermore, the investigation activities in each case study seek to understand, for knowledge workers participate in these industrial practices, what were the key issues related to capturing and utilisation of context. This purpose had impacts on cases study methods that was applied, this is discussed in Section 4.2.

4.2 Case Study Methods

As mentioned in Section 4.1, industrial practices are in place in Airbus to capture design experience and repair experience in the form of digital information. For repair experience, a case study was performed to understand how the Wing In-Service Support department capture and reuse their repair experience. For design experience, a case study was performed to understand how lessons-learn are captured and reused, firstly with organisation standard practices and secondly with the Fuel System department.

The focus of these case studies was to understand what contextual information were required in the creation, organisation and use of repair experience and lessons-learnt. For this reasons, the case study method need to interpret and consider core elements of knowledge workers' activity. Among existing literature, various frameworks have been proposed for studying context of human activities such as situated action models, activity theory and distributed cognition (Nardi, 1996). Among these approaches, the concepts in activity theory were most suitable for this research. In activity theory, the unit of analysis is an activity which is composed of subject, object, actions and operations (Leont'ev, 1974), as outlined below:

- *Subject*: An subject is a person or a group engaged in an activity
- *Object*: An object is held by the subject and motivates activity.

- *Actions*: Actions are goal-directed process that must be undertaken to fulfil the objects
- *Operations*: Operations the way actions are actually carried out.

According to the concepts outlined above, and in the frame of this research: the subjects were aerospace engineer; the object was the objective to capture and reuse engineering experience; the actions included various tasks to create, organise and use information that capture engineering experience; and finally the operations corresponded to how such actions were carried out operationally in the industrial practices to be studied. To understand the context the industrial practices to be studied, the following need to be studied: Engineers who work with the targeted industrial practices; the motivation and rationale of capturing and reusing engineering experience; what actions were taken to perform in such industrial practices; and how these actions were enabled by cooperation or departmental methods and tools.

Based on above discussion, ideally for each case study, the detailed engineering workflow shall be mapped, typical types of engineers involved shall be identified and studied, key information tools used to enable the industrial practices shall be described. However, as pointed out by Blessing and Chakrabarti (2009, p. 105), for researches grounded in industrial setting, the approach taken is often impacted by operational factor such as availability of intended participants and information confidentiality. In the case of this research, the following factors determined that the two cases studies were conducted in different manner: 1) the availability to the aerospace engineer working on two types of industrial practice; and 2) the specific nature of each type of industrial practices. These are discussed in the following text.

In the case study for repair experience, the author undertook 3 months placement to in the Wing In-Service Support department to perform participant observation[3]. Within this period, the author performed interviews with engineers to: 1) understand key information elements that were required in different stages of their workflow; and 2) identify key context related issue in their practice of capture and reuse repair case documents. A detailed study was carried out to examined departmental related to skill profiles of engineers, information tools as well as in-service repair process. A report on this placement is available in Appendix B

As for the lessons-learnt case study, the long cycle of related engineering processes make similar action research impractical − the duration of lessons-learnt document creation and usage often take places across different stages of Aircraft development programme, with months or years timespan between. For this reason, the case study started with studying on corporate level information tool and existing information related to lessons-learnt creation and usage. In the second part of this case study, the focus moved toward the lessons-learnt practices of Fuel System. Due to availability of Fuel System personnel, this part of the case study was conducted in the form of two workshops with Fuel System knowledge management team members to understand how lessons-learnt activities took place inside

[3] The author undertook this study in the form of placement as part of an EADS internal research project on the subject of information push technology.

this specific engineering domain. Additionally, the author took part in technical review meetings of the corporate standard lessons-learnt tool to understand user issues.

As for the lessons-learnt case study, the long cycle of related engineering processes make similar action research impractical − the duration of lessons-learnt document creation and usage often take places across different stages of Aircraft development programme, with months or years timespan between. For this reason, the case study started with studying on corporate level information tool and existing information related to lessons-learnt creation and usage. In the second part of this case study, the focus moved toward the lessons-learnt practices of Fuel System. Due to availability of Fuel System personnel, this part of the case study was conducted in the form of two workshops with Fuel System knowledge management team members to understand how lessons-learnt activities took place inside this specific engineering domain. Additionally, the author took part in technical review meetings of the corporate standard lessons-learnt tool to understand user issues.

The discussion now moves onto to presentations of industrial case studies, starting with practices to capture and reuse repair experience in In-Service in Section 4.3, and followed by the lessons-learnt practices in Section 4.4.

4.3 Capturing and Reusing of Repair Experience

The Wing In-Service Support department featured in this case study is responsible for repairs associated with the aircraft wing structure. They provide support on a 24-hour-a-day, 365-day-a-year basis to design and validate repairs inquires by airlines customers. At the time of study, the department employed about 100 engineers in Filton (UK) and Wichita (USA).

4.3.1 In-Service Support Engineering Workflow

Workflows depicting ISS engineering activities are presented in this subsection. Firstly the top level repair workflow is presented, detailing the interactions between Airline customer, Customer Service and In-Service Support. This is then followed by internal workflow within Wing ISS.

Top Level Repair Workflow

Within Airbus, repair inquires from airline customers are mainly handled by two organisational entities: **C**ustomer **S**ervice (**CS**), and **I**n-**S**ervice **S**upport (**ISS**). CS serves as the customer focus point. They receive repair inquires from airline customers , document and distribute them to the corresponding ISS department based on which aircraft major components (landing gear, wing, fuselage fuel system, etc.) each inquiry is related to, they also perform tracking and set repair deadline for in-service support departments to deliver repair solutions. The typical workflow about a repair inquiry between airline customer, CS and ISS is described by Airbus internal process document (Airbus S.A.S., 2013), and is depicted in the sequence diagram shown in Figure 4-1.

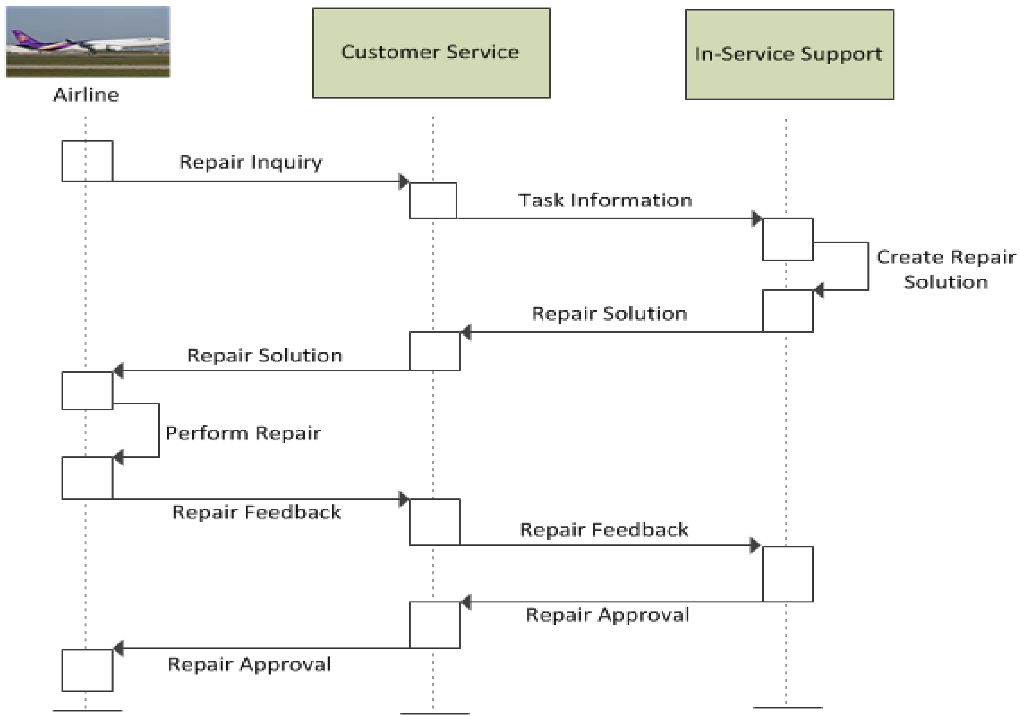


Figure 4-1: Top level repair workflow

As seen in Figure 4-1 the main steps are as follows:

1. A repair inquiry is firstly originated by airline customer
2. The repair inquiry is received and distributed by CS to appropriate ISS department.
3. The ISS department creates the repair solution.
4. The repair solution is performed in concerned aircraft, either by Airbus, third party maintenance provider or the airline customer themselves.
5. The airline customer informs Airbus the detail of the repair.
6. Airbus approves the repair.

For the Wing ISS department featured in this case study, the repair requests principally can be classified into two types: major repairs which require significant support such as an on-site repair party; and Daily In-Service Query (ISQ) which require routine provision to the airline of repair instructions for on-site implementation, typically repair solution for a daily repair is less complex compare to that of a major repair.

In-Service Daily Query (ISQ) Workflow in Wing ISS

It was decided that the case study will focus on investigating the engineering work associated with the Daily In-Service Query (ISQ) for the following reasons:

- Daily repairs represent the majority (about 95%) [4]of the repair inquires.
- The nature of the engineering work on daily repair has very high demand on reusing encoded knowledge in the form of repair case documents.

[4] Wing In-Service internal statistic, studied in march 2009.

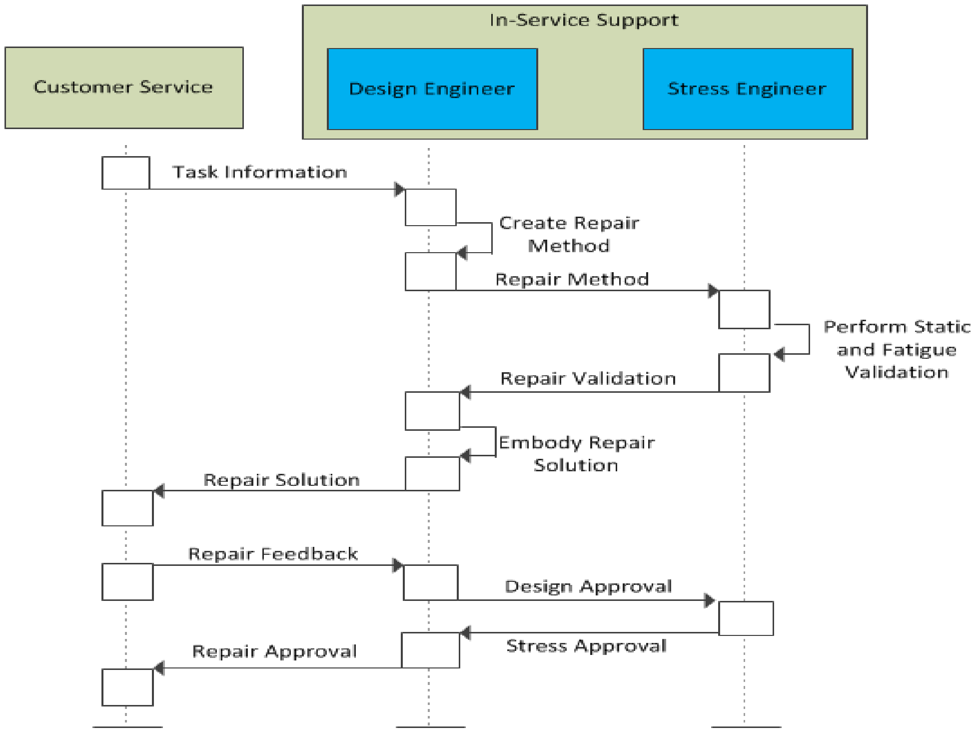


Figure 4-2 In-Service Daily Query Workflow

The workflow of a daily repair was documented in ISS internal procedural (Airbus Wing In-Service Support Department, 2009), and is depicted in the sequence diagram in Figure 4-2. This work flow can be summarised in the following generic steps:

1. New repair task from CS is assigned to a design engineer and a stress engineer[5].
2. The design engineer designs the repair methods and purposes the solutions.
3. The stress engineer performs stress calculation to validate the proposed repair solution from both static and fatigue perspective.
4. The design engineer embodies the repair solutions which include the repair methods and the stress validation.
5. The design engineer sends the repair solution to CS, who will provide the repair solution to the airline customer and wait for repair feedback from the airline customer, as depicted in Figure 4-1.
6. When the repair feedback is received from Customer Support, the design engineer performs repair approval from design perspective.
7. The stress engineer performs repair approval from stress perspective.
8. The design engineer issues the repair approval.

For a typical daily repair inquiry, the time allowed for Wing In-Service Support to provide repair solution, as seen in step 5 above, to CS is usually between 4-6 hours. The on-time response rate to daily repair is a key performance indicator (KPI) for the department. In addition to this, they are also assessed based on the accuracy and consistency of their repair solutions.

[5] In some cases, the stress work is split between two stress engineers, one specialised in static stress, one specialised in fatigue and damage tolerance (F&DT)

4.3.2 In-Service Engineers Knowledge

As shown in the workflow for daily repair above, the Wing In-Service Support department mainly employ engineers from two engineering disciplines:

- **Design**[6]: Knowledge topics associated with the design disciplines are such as: Concept development, Metallic Design, Composite Design, Digital Mock-Up (DMU), Structure Certification Process and Airworthiness.
- **Stress**: Knowledge topics associated with the stress disciplines are such as: Fatigue and Damage Tolerance, Stress Analysis numerical simulation, Particular Risk Analysis, Finite element modelling, Thermal and Optimisation.

The generic knowledge of core engineering discipline is considered to be the fundamental requirements that the engineers need to possess within the aerospace industry. Building on these generic engineering knowledge types, the following knowledge types are required for repair engineer to operate efficiently within the In-Service environment. These include:

- **Product knowledge:** about airbus aircrafts such as wing structure and internal cabling installation.
- **Repair specific knowledge:** such as the nature of various types of structural damage, and the application of treatment.
- **Procedural knowledge:** various aviation standard and organisational procedures.
- **Engineering informational tools:**
- **Past repair experience**: This is the tacit knowledge an engineer acquire as he/she participate in In-Service repair activity.

After summarising the above knowledge types, the author performed interview sections with two design engineers and two stress engineers to identify key information elements that are required in different stages of the ISQ workflow and associated each information element to the knowledge types required for ISS engineers. The interviewed engineers also highlight the information repository where they obtain different information element from. This can be seen in the author's In-Service placement report in Appendix B. The required information elements are highlight in the red in the following Figure 4-3.

[6] Key knowledge of In-Service engineers are identified by studying and summarising Internal Airbus skill profiles for In-Service Support employees

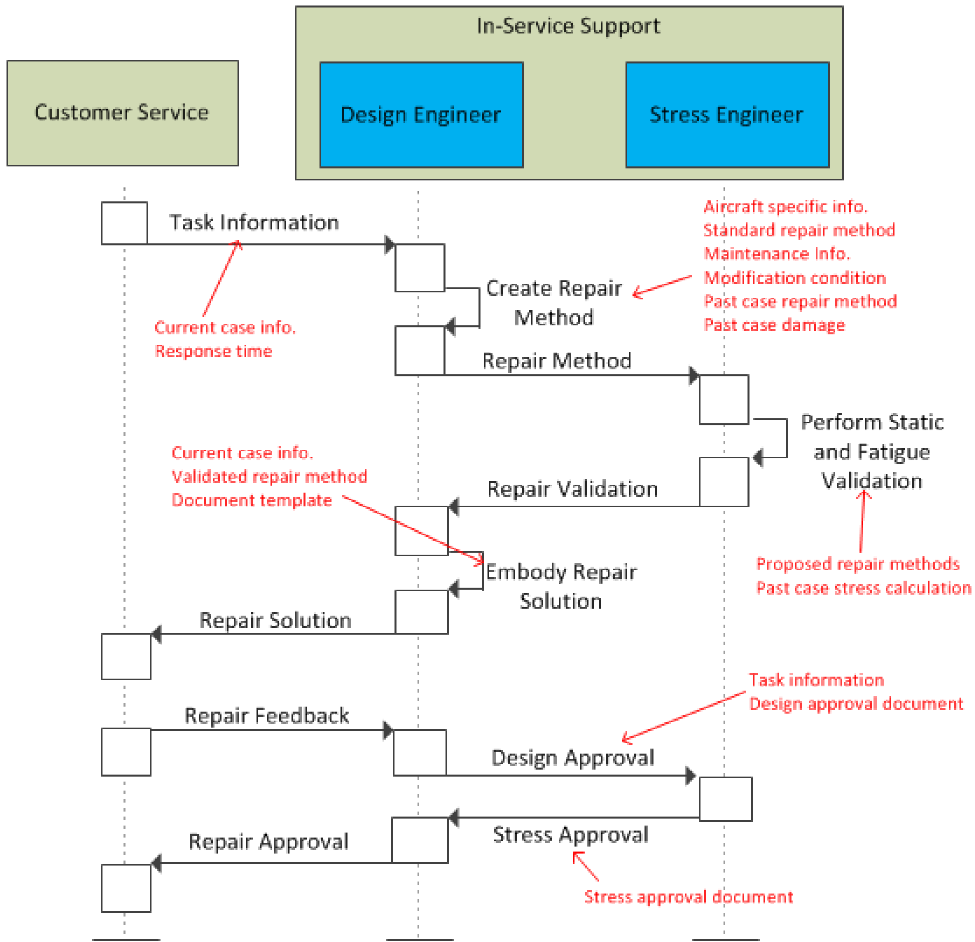


Figure 4-3: Information elements required to handle daily repair (ISQ)

As illustrated in Figure 4-3, various element of engineering information are shown as red item in the workflow. The following Table 4-1 gives a more detailed description of each of the information elements. In this table, the associated knowledge type is identified, to indicate that how different types of engineering knowledge contribute to the engineering process.

Information Element	Description	Associated Knowledge Type
Aircraft family specific information	Specific information related to the aircraft family (aircraft model) which the aircraft concerned in the current repair task belongs to.	Product knowledge
Standard Repair Methods	Standardise repair methods for aircraft damage specific to aircraft family.	Repair knowledge Design knowledge Repair specific knowledge
Maintenance Information	The maintenance history of the aircraft concerned in the current repair task	Repair specific knowledge Past repair experience
Modification condition	Product modification history of the aircraft model which the concerned aircraft belong to.	Product knowledge

Current Case Information	Basic information about the current repair task, such as airline, aircraft serial number, damage information (location & level) etc.	NA - Provided by Customer Service, not associated with specific knowledge type.
Response Time	Request response time by CS	NA - Provided by Customer Service, not associated with specific knowledge type.
Past Case Damage	Damage information of similar past repair cases	Past repair experience Repair specific knowledge
Past Case Repair Methods	Repair method used in similar past repair cases	Past repair experience Design knowledge
Past Case Stress Calculation	Calculation methods used in similar past repair cases	Past repair experience Stress knowledge
Document template	Document templates that are used to standardised engineering deliverable requested by various stage of the official work flow(e.g. Repair solution, stress validation and repair approval)	Procedural knowledge

Table 4-1: Information elements

As shown in Table 4-1, among various types of knowledge that is identified, past repair experience was associated to more information elements (4 out of 10) than any other type of knowledge. It was mentioned by the interviewed engineers that the experience of past repair cases is considered to be critical to achieve on-time response for ISQ. At the time of the study, the Wing ISS had set aside substantial resource to establish a routine process to capture and manage repair case information. For the rest of this section, this will be focus of the discussion.

4.3.3 Repair Experience Capturing and Reuse

In this subsection, the process within Wing ISS to capture and reuse repair experience in the form of repair case document is introduced. In the following text, firstly the rationale of this process is discussed, followed by detailed description of this process, and finally study on the repair cases documents are presented.

Rationale of a dedicated repair experience capturing process

As discussed in subsection 4.3.2, experience of past repair is regarded as critical knowledge to ensure on-time response for in coming daily ISQ. Such past repair experience contains the application of different types of engineer knowledge in a contextualised manner, and one can only acquire it by taking part in in-service task during long period. In addition to this, it is also observed that, such past repair experience is more than the experience in application of engineering knowledge. It was also about knowing where and how to find valuable information.

For example, one of the most recognisable quality of experienced repair engineers is the ability in locating information (i.e. Document, drawing) that is useful among past repair cases. When describing one of the most experienced engineers, the chief design of Wing ISS said “*He is a walking cyclopedia, we used to keep paper copies of our old repair cases in the file cabinets, and he would say ‘go to that cabinet in the middle aisle, you can find a repair case file in the middle shelf with certain case number, and around the middle section of that file there is a picture that would be useful for your job!*”

At the time of the study, there was no corporate process and tool dedicated to the capturing to such past repair experience. To gain information about past repair experiences, engineers needed to either consult with senior engineers who had been in the department for many years, or gather required information from various information repositories. However, both of these options were not deemed to be sustainable. In interviews, department manager and team leaders had mentioned that it was becoming increasingly difficult to replace senior engineers as they retired while some of them were already working beyond retiring age.

From an information system aspect, it was difficult for engineers to obtain past repair information from various organisational information systems, as listed in Appendix C. Information for aircraft products come into in-service in different time periods were often stored in different information systems which were not inter-connected. This lack of integrated information source created natural barrier for engineers to correlated different pieces of information in a contextual manner. In the other hand, development of such a integrated information system dedicated to specific engineering tasks were considered to be too time consuming and expensive.

It was based on the above discussion that Wing ISS department developed a process for capturing and reuse of repair case information. The purpose was to enable engineers to search for past repair cases similar to the task at hand. This will be discussed in detail in the following text.

Process for repair case capturing and reuse

Since 2005, the Wing ISS department started to dedicate resource to establish a process to allow capturing and reuse of repair experience. With this process, repair case documents were created as daily ISQs were dealt with. Additionally, work was conducted to retrospectively creating repair cases documents for previous ISQs as far back as 1980s.

A repair case administration team was put in place to perform the embodiment and organisation of the repair case document. This team was led by a repair case curator who is a senior design engineer with in-depth experience in handling repair tasks. The repair curator’s main task was to provide quality control to the repair case documents.

The aim of these repair case documents is to provide a "complete story" of a given daily ISQ in terms of nature of damage, exchange between different parties involved, repair methods used and stress calculations applied. The key steps of this practice are described as the following:

- **Creation:** A repair case document in PDF format is created when a repair case is finalised. Each document contains key information elements used during the handling of the case, taken from various enterprise systems. Such information includes customer emails, damage photos, related drawings, repair method description and stress validation.

- **Organisation:** These repair case documents were categorised and organised using allocation guideline based on product taxonomy, and stored in folder/file structure corporate share drive. An example of these storage structure is shown in Figure 4-4 below:

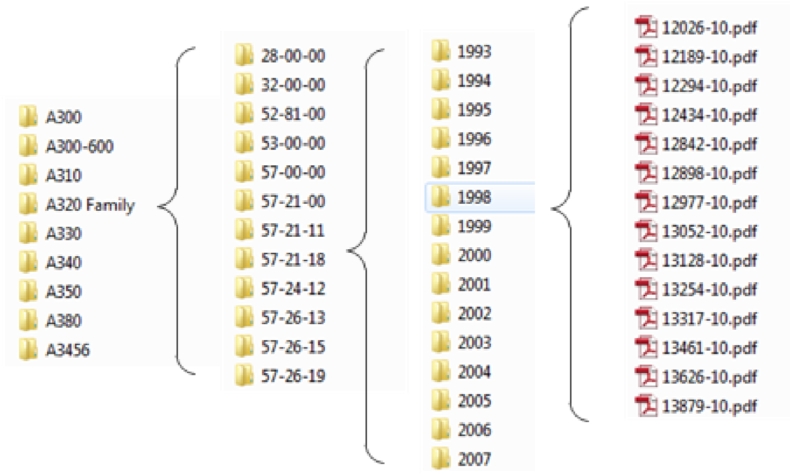


Figure 4-4: Storage structure of repair case documents

- **Retrieval:** A record for each repair case document is created in a Microsoft Excel spreadsheet which contains key metadata of repair cases in tabular format, as shown in Figure 4-5 Below, Excel VBA Marco is then used to programmatically recreate hyperlink to the actual repair case document by analysing the metadata. It is worth noting that direct access to the repair case documents is inefficient due to the shear amount of documents and lack of repair case context when accessing via folder/file structure.

AIRBUS | ATA File / RAS | A320 Family - Repair Archive 2004>

Select Row or Cell and Press Button For ATA File or RAS. Any Missing Files Notify

ISQ No	In Date	Title	MS	ATA	A/C Type	A/L
12243/2010	02-Feb-10	LH WING LWR SKIN MAN HOLE 540PB SURROUND HOLES DAMAGE	834	57-21-11	A320-200	
12241/2010	01-Feb-10	Fan Cowl loss, LH Wing - damage to L/E closing rib	3672	57-00-00	A320-200	
12236/2010	01-Feb-10	LH WING CORROSION UPPER SURFACE	2105	57-21-11	A321-200	
12233/2010	01-Feb-10	Corrosion, Top skin Pnl #2, Lower Surface, T/E between Rib 14-19, LH Wing	3129	57-21-11	A320-200	
12231/2010	31-Jan-10	Replacement, Retraction Jack Anchorage Fittings, Both Wings	677	57-26-13	A320-200	
12235/2010	29-Jan-10	RH TOP WING SKIN CORROSION STRG11	2122	57-21-11	A319-100	
12230/2010	29-Jan-10	Crack, Leading Edge Skin #6, Slat Track 6-7, LH Wing	533	57-41-11	A320-200	
12228/2010	29-Jan-10	Fan Cowl loss, LH Wing	3672	57-21-11	A320-200	
12226/2010	29-Jan-10	Query, Tab Washer Part Number, Rear Pylon Pick-up Fitting	983	57-26-19	A321-200	
12227/2010	29-Jan-10	Corrosion, Forward Pylon Pickup Bushes, Right Hand Wing.	291	57-26-19	A320-200	
12224/2010	28-Jan-10	Corrosion, Bore Outboard Lug, Side Stay Fitting, LH Wing.	792	57-26-13	A321-200	
12223/2010	28-Jan-10	Corrosion, Bore, Side Stay Fitting Outboard Lug, RH Wing	792	57-26-13	A321-200	
12218/2010	28-Jan-10	Oversize Hole, Flap Track #3, Fairing Bracket, RH Wing	732	57-55-11	A319-100	
12217/2010	28-Jan-10	Chafing, Flap Track #3, Lower Side Stay, RH Wing	1194	57-55-11	A320-200	
12215/2010	28-Jan-10	Crack, MLG Gear Support Rib 5 fwd Lug, RH Wing	1269	57-26-13	A319-100	
12214/2010	27-Jan-10	Bulge, Seal Plate Rib 21 Spoiler 5, Right Hand Wing	624		A320-200	
12213/2010	27-Jan-10	Corrosion, Top Skin Panel 1, Spar Bolting at Rib 8/9 area, RH Wing.	2196	57-21-11	A319-100	
12211/2010	27-Jan-10	Gouge, Aileron Lower Access Panel 575LB, LH Wing	721	57-51-37	A319-100	
12210/2010	27-Jan-10	Puncture, T/E Access Panel 573AB, LH Wing	721	57-51-37	A319-100	
12207/2010	27-Jan-10	Corrosion at Bonding Spigot, Ribs 19-20, Front Spar, Top Skin, Panel 2, LH Wing.	235	57-21-11	A320-200	
12205/2010	27-Jan-10	CORROSION RH TE TOP SKIN LOWER SURFACE	774	57-21-11	A320-200	
12203/2010	27-Jan-10	FUEL LEAK/CORROSION, TOP SKIN, RH WING	438	57-21-11	A320-200	
12201/2010	26-Jan-10	RH WING TOP SKIN CORROSION	235	57-21-11	A320-200	
12202/2010	26-Jan-10	Corrosion, Lower Surface, Bottom Skin, Right Hand Wing	331	57-21-11	A320-200	
12199/2010	26-Jan-10	Minor Gouge, MLG Rib 5, RH Wing	153	57-26-13	A320-200	

Figure 4-5: In-Service Repair Case Spreadsheet

- **Maintenance:** The repair case curator oversees the creation and storage of repair case documents and maintains the spreadsheet full time. Typical tasks include removing inappropriate information, reviewing and update repair case metadata in the spreadsheet.

In the following text, study on this repair cases collection during the case study is presented.

Repair cases documents

The repair cases documents were archived separately in three repositories, this was according to the three aircraft product categories: SA (Single Aisle - A320 Family), WB&LR (Wide body and long range aircraft – A300, A310, A330 and A340), and A380. For the SA and WB & LR, each repair cases repository were further divided into two sections Pre-2004 (before 2004) and Aft-2004(after 2004) for legacy reasons. The number of repair case documents in each repository at the time of this case study is shown in Table 4-2:

SA		WB & LR		A380
Pre 2004	**Aft 2004**	**Pre 2004**	**Aft 2004**	
5278	8998	9100	7966	740

Table 4-2: Number of repair case documents in each repository

At the time of study, there was a total of more than 30,000 repair case documents created. As mentioned above, this collection of repair cases was not stored in a purpose-built enterprise database. The repair cases themselves, individually, were not considered as official information with technical authority such as the Standard Repair manual, yet they were a vital and essential resource to the engineers. Thus this collection of repair case documents were recognized as a very important asset in the Wing In-Service department for two purposes:

1. As knowledge source that provide technical knowledge contextualised in the form of actual repair cases.
2. As an information source that provides quick access to many information elements that were needed for producing repair solution.

As more and more aircraft are sold, the department need to cope with increasing number of cases. The following Figure 4-6 visualises the number of repair cases break down by year in generally increasing trend.

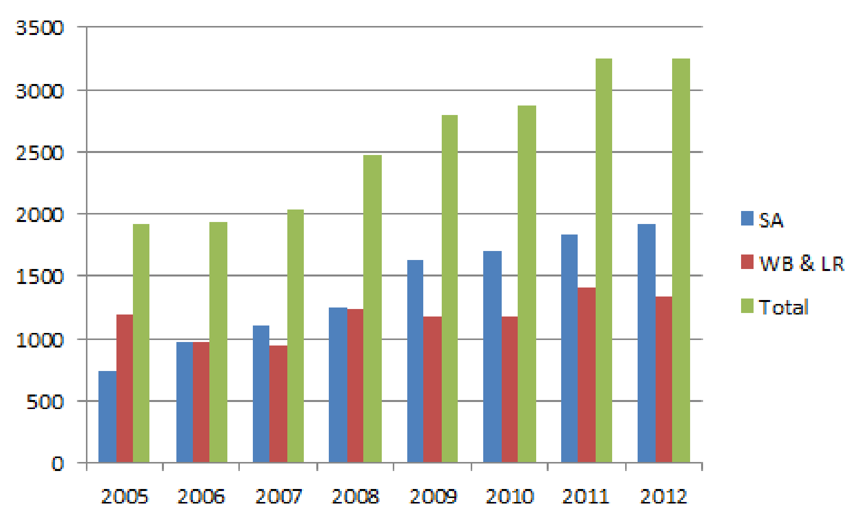


Figure 4-6: Number of repair cases on annual basis 2005 - 2012

It was also clear that as time goes on, according to Wing-ISS internal statistic, more and more space was allocated to the storage of repair case documents. As shown in Figure 4-7 below, the volume usage in the share drive had been increasing year-on-year[7].

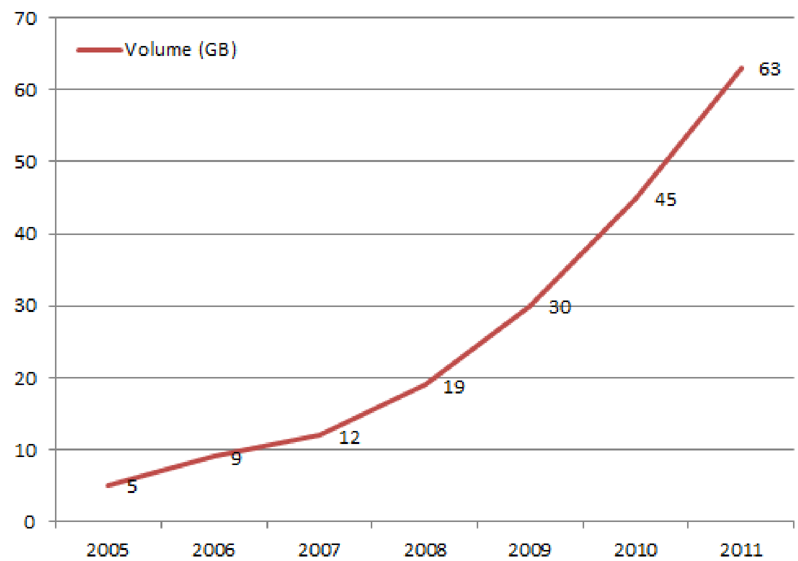


Figure 4-7: Total volume usage (GB) of repair case document from 2005 to 2012

4.3.4 Context Related Issues for Repair Experience Capturing and Reuse in Wing ISS

From subsections 4.3.1 to 4.3.3, detailed descriptions about the engineering process of handling daily ISQ are presented. In particular, information elements required to produce the repair solution are identify. The practice of capturing and reuse repair experience in the form on repair cases document is then introduced.

Discussion provided in this subsection will now focus on the key context related issues faced by engineers to capture and reuse repair case documents in this practice. In order to study this, 9 interviews were performed with Wing ISS personnel of different position, engineering disciplines and experience. The detailed result of these interviews is presented in Appendix C. An overview of context related issue mentioned by the interviewees, alongside with number of mentioning a given issue, is presented in the Table 4-3.

Issues	Number of interviewees mentioning (out of 9 interviewees)
Support of domain semantics	7
Repair case documents usage	7
Connection between related information	7
Taking historical context into account	5
Information summary	4
Collaboration support	3
View progress of on-going cases	2

Table 4-3: Context related issues mentioned by Wing ISS interviewees

Among context related issues listed in Table 4-3, 6 were mentioned by 4 or more interviewees. These were considered as key context related issues faced by engineers in

[7] Statistic on repair case document volume usage was studied at August 2011

the practice of repair cases capturing and reuse. Detailed description of each of these 6 issues is provided in the following:

- **Support of domain semantics**: It was mentioned that many of the concepts used in the repair domain are inter-related. For example, damage such as dent, gouge and scratch were often similar to each other, and consequently the repair methods could be similar. Similarly, repair for similar product structure such as different ribs (e.g., Rib 1 to Rib 15), and flap track (e.g., flap track 1 to flap track 4) are also similar. However, the current filtering facility provided by Excel spreadsheet can not recognise these types of semantic relationships. At the time of the study, engineers had to search for semantically related terms manually one by one. It was recognised that relationships between these domain concepts are not easy to grasp especially for engineers who are new to the repair domain.

- **Repair case documents usage:** At the time of the study, there was no possibility to monitor how the repair case document were searched and used. Interviewee mentioned that engineers had been using different term for filtering even while working on new cases with same damage on same location. There was no way to guarantee that the quality of filtering result on the Excel spreadsheet. Secondly, it would be much beneficial if the usage of individual repair case can be tracked so that the various businesses intelligent can be extracted. For example, a commonly used repair case document might contain repair methods that can be standardised for common damage.

- **Connection between related information:** Although different repositories often provided similar information, in many cases there is subtle difference in terms of the specific information element that is available, and it is often difficult without in-depth investigation to understand how to access such related information. For example, different drawing repositories might provide different view on the same part, and engineers often need to compare and contrast different drawing of the same parts to find out the one that provided required information such as part dimensions. It was mentioned that it would be highly desirable if potentially connected information can be prompted when examining repair case documents.

- **Taking historical context into account:** Design of repair solution often need to take into account the repair history of the aircraft concern. For example, previous repair in the same damage location will add extra complexity as the standard product information would no longer be applicable. In some situation, previous repair in closely located part will also have to be considered for stress and fatigue calculation. It was considered that the repair case search facility being used at the time of study was not able to take such historical context into account. For example, although repair case documents present a complete picture of how a repair case was handled, the information captured within the documents may be out of date and is no longer feasible for current engineering practices

- **Information summary:** At the time of study, the repair case Excel spreadsheet did not take account of what is available within repair documents such as photos and key document references. After initial filtering via the spreadsheet, engineers need to open each potential repair case document to perform detailed study on the usefulness of the case. Such documents often amount to large number of pages, and currently there is no facility to provide information summary to spare detailed examination effort. This was mentioned to be a particular issue for off-site access as well as ISS engineers in Wichita where connection to the corporate share drive was often slow.

This list of key context related issues were the main outcome of this case study on Wing ISS practice to capture and reuse repair experience. This will be discussed and consolidated in Section 4.5 with the key findings from the case study of lessons-learnt practice. This second case study is presented in Section 4.4.

4.4 Lessons-learnt Practice

In this section, the second case study about industrial practices of knowledge work is presented. The practices featured in this case study facilitate capturing and reuse of lessons-learnt within Airbus. Within Airbus, lessons-learnt are defined as "*short pieces of experience that may contain positive or negative experience*" (Airbus S.A.S, 2004). Such practices allows engineers the opportunity to document the context of encountered issues, describe specific solutions applied, reflect on experience generated from handling such issues and record any update to related best practices due to this experience. The purpose is to capture engineering knowledge that is accumulated in previous work, and allow the captured knowledge to be reuse both within single organisation entity and company wide across different entities

As a knowledge management practices, there is much coverage about lessons-learnt processes or systems in existing literature, such as the work of O'Leary (1998), Prencipe & Tell (2001) and Web & Aha (2002). This case study aims to give an account on how the practice of lessons-learnt is being implemented within Airbus. The finding of this case study contribute to defining how application of context aware systems can support aerospace knowledge work, as discussed firstly in Section 4.5 and then in Chapter 5.

Within this section, firstly corporate process and tool that enable lessons-learnt capturing and reuse are discussed in subsection 4.4.1. The discussion in subsection 4.4.2 then focuses on how lessons-learnt practice was facilitated in the Fuel System engineering domain. Finally, the context related issues identified from this case study are presented in subsection 4.4.3.

4.4.1 Corporate Process and Tool for lessons-learnt Activities

In this subsection, corporate process and tool to facilitated lessons-learnt capturing and reuse are introduced. This is followed by a discussion on the current usage of the corporate lessons-learnt tool RISE.

Corporate process and tool

As the official knowledge management service provider in Airbus, Airbus Knowledge Management had developed and deployed a company wide lessons-learnt system called RISE for departments across the company to create and share lessons-learnt documents. The system RISE allows Airbus employee to follow through the following process to populate, validate and facilitate the reuse of lessons-learnt document:

- **Authoring:** Any employee can create lessons-learnt documents and submit them to the RISE system in "to be validated" status. Such lessons-learnt documents allow the author to specify information elements such as subject, lessons-learnt context, applied solution, recommendation, attachment as well as various metadata related to the experience to be captured.
- **Coordination:** lessons-learnt coordinator provides coordination service to manage the validation process of lessons-learnt document, this include the identification of appropriate domain expert to perform validation, as well as facilitating necessary discussion and performing administrative tasks.
- **Validation:** Domain experts belonging to the designated domain of a given "to be validated" lesson-learnt performs validation on the content of the lesson learnt document. Once a lessons-learnt document is validated, it becomes available to employees in the company to search and reuse.
- **Reuse:** The system RISE provides search engine facility, so that employee in the company can perform text-based search for any validated lessons-learnt document, and then to view or download any chosen lessons-learnt document.

Usage of official process and tool

Although such a company-wide tool is provided, at the time of the study, the practice to capture and reuse of lessons-learnt is far from being standardized within in Airbus. An Internal review (Airbus S.A.S, 2008) in 2008 examining the lessons-learnt processes on A350 programme revealed the degree of variety of how such information is captured among different departments in the UK. An overview of lessons-learnt practices in five Airbus departments is presented in the Table 4-4 below:

Department	Process & Tool	Information elements	Number of Lessons Leant
Fuel System	**Process:** Full cycle creation and review process **Lessons-learnt Document:** Word document **Management & retrieval**: Excel spreadsheet **Integration with RISE**: Not mentioned	- Problem experience - Specific Solutions - Recommendation - Observation - Status - Evidence of Re-use	451
Landing Gear	**Process:** No systematic process, driven by team leaders to perform analysis. **Lessons-learnt document:** PowerPoint **Management and retrieval:** Excel spreadsheet **Integration with RISE:** On-going	- Problem description - Solution - Impact - Status - Rationale	90
Wing	**Process:** Lesson learnt captured during analysis activity of other engineering process. Only major in-service issues are captured as lessons-learnt. **Lessons-Learnt Document:** Excel spreadsheet **Management & retrieval**: Excel spreadsheet **Integration with RISE**: Validated lessons-learnt document are migrated to RISE	- Short Title - Requirement - Rationale - Technical follow up - Status	16
Inerting Systems	**Process:** Ac-hoc process, formal process under development	- Title - Description	17

	Lessons-Learnt Document: Excel spreadsheet **Management & retrieval**: Excel spreadsheet **Integration with RISE**: Not mentioned	- Risk Level - Mitigation Action	
Wing Anti-Ice	No activity taken to capture lessons-learnt	Not captured	None

Table 4-4: Overview of lessons-learnt practices in five Airbus UK departments, based on internal review on lessons-learnt usage (Airbus S.A.S, 2008)

As shown in Table 4-4, the practices for lessons-learnt varied greatly among departments that was studied, ranging from having full cycle creation and review process in Fuel System to lack of any lessons-learnt activity in Wing Anti-Ice. Among the departments studied, the usage of the corporate lessons-learnt tool RISE is not wide-spread – only two departments featured in this study used RISE.

In this study, the most prevalent tool used in this study is the Excel spreadsheet, with Word document or PowerPoint presentations being used to cover lesson learnt with in-depth technical information. Another striking point from this study was the un-even distribution of number of lesson learnt generated. Fuel System, aside from having the most mature process, had generated by far the largest number of lessons-learnt documents.

The RISE tool does provide facilities to support the creation of lessons-learnt documents through to the review and approval stage. However, it was observed that these built-in facilities are NOT being used by the engineering department featured in the internal lessons-learnt study.

After studying this internal study, a decision was taken to not to further investigate the practices of lessons-learnt using the company tool RISE. Since it was apparent that the usage of this tool does not seem to represent the as-is status of lessons-learnt practice within Airbus. More importantly, there is low visibility as to how the captured lessons-learnt document would be used in actual engineering process by observing information in RISE. The second half of this case study therefore focused on the lessons-learnt study within Fuel System, the department that had the most mature process and had generated the biggest number of lessons-learnt. This is presented in subsection 4.4.2.

4.4.2 Lessons-learnt Practices in Fuel System

The second half of this case study focused on lessons-learnt practices in Fuel System and is presented in this subsection. This took place in the form of two workshops with the domain knowledge management team of Fuel System. The key points emerged from these two workshop are summarised in two mind maps in Appendix C. Additionally, the author studied departmental documents related to their lessons-learnt practice.

The Fuel System department is responsible for all activities related to aircraft fuel system, and fully cover each aircraft model of the product portfolio. These include high-level strategic decisions making, design of fuel system, research, development of next generation technological capability, monitoring production of existing designs, and providing in-service support to all aircrafts in operation.

For this reason, comparing to the Wing ISS department, the Fuel System department covers wider variety of engineering tasks and also engages with more internal and external entities. Comparing to repair case process in the first case study, the lessons-learnt document process of Fuel Systems aims to ensure experience accumulated during various activities are captured and shared among the group as well as communities across the organization.

In the following text, the discussion started with introducing the reuse of lesson learnt during engineering design review. This is to clarify the purpose of capturing lessons-learnt with this department from an engineering design perspective. After this, the process to capture and manage lessons-learnt documents is introduced.

Reuse of lessons-learnt for design review

During the aircraft development process, a series of design reviews are required to take place at various critical stages to determine if the development can proceed to the next maturity level. Such design review meetings require the development team to demonstrate compliance to product requirements by demonstrating relevant evidence. Such evidence includes demonstration of reuse of appropriate lessons-learnt.

In order to meet with this requirement of lessons-learnt reuse in a rigours manner, the Fuel Department established the following process to review their lessons-learnt repository and perform technical follow up:

1. **Initial review:** Existing lessons-learnt documents are reviewed by domain experts. The ones that have potential high impact for current project phase are identified.
2. **Allocation:** High impact lessons-learnt documents are allocated to engineers who can benefit from learning and reuse the captured information.
3. **Review:** Engineers review the lessons-learnt documents that are allocated to them; and take the captured information into account during their tasks.
4. **Iteration:** The above process is iterated throughout the product development cycle. Lessons-learnt are reviewed and allocated, before the start of engineering activities leading to each design reviews

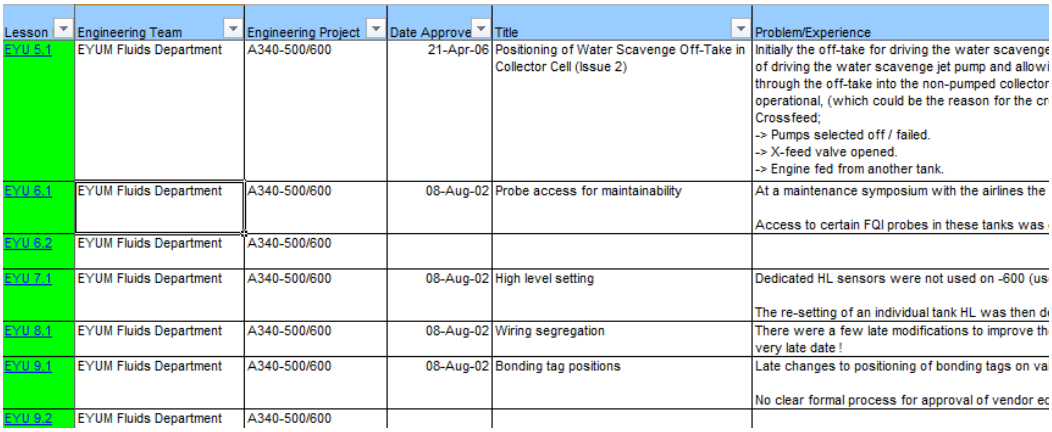
It is worth noting that, at the initial review stage of this process, not only lessons-learnt document are reviewed. The domain experts also carried out review on other potential applicable information such as engineering methods that are captured best practices. This will be further discussed in subsection 4.4.3.

Lessons-learnt documents capturing and management

The main mission of the domain knowledge management team of Fuel System was to facilitate the capturing of lessons-learnt in the form of lessons-learnt document, as well as performing technical task such as storing lessons-learnt document in shared folders according to appropriate knowledge stream. Each lessons-learnt document is created and organized by the following process:

1. **Creation:** Each lessons-learnt document is created by the owner of a knowledge stream in Microsoft Word format. Each knowledge stream represents a key knowledge category of the fuel system domain. Each knowledge stream owner is an expert in the respective knowledge category.

2. **Storage:** Each lessons-learnt document is sorted and stored within corporate shared drive following allocation guidelines agreed by domain experts.
3. **Retrieval:** The lessons-learnt document is available for retrieval by 1) directly accessing the stored location, or 2) via a summary Excel spreadsheet that contain metadata for each LL in tabular format and hyperlink to the stored location. Figure 4-8 shows part of this Excel spreadsheet.



Lesson	Engineering Team	Engineering Project	Date Approve	Title	Problem/Experience
EYU 5.1	EYUM Fluids Department	A340-500/600	21-Apr-06	Positioning of Water Scavenge Off-Take in Collector Cell (Issue 2)	Initially the off-take for driving the water scavenge of driving the water scavenge jet pump and allowi through the off-take into the non-pumped collector operational, (which could be the reason for the cr Crossfeed; -> Pumps selected off / failed. -> X-feed valve opened. -> Engine fed from another tank.
EYU 6.1	EYUM Fluids Department	A340-500/600	08-Aug-02	Probe access for maintainability	At a maintenance symposium with the airlines the Access to certain FQI probes in these tanks was
EYU 6.2	EYUM Fluids Department	A340-500/600			
EYU 7.1	EYUM Fluids Department	A340-500/600	08-Aug-02	High level setting	Dedicated HL sensors were not used on -600 (us The re-setting of an individual tank HL was then d
EYU 8.1	EYUM Fluids Department	A340-500/600	08-Aug-02	Wiring segregation	There were a few late modifications to improve th very late date !
EYU 9.1	EYUM Fluids Department	A340-500/600	08-Aug-02	Bonding tag positions	Late changes to positioning of bonding tags on va No clear formal process for approval of vendor ec
EYU 9.2	EYUM Fluids Department	A340-500/600			

Figure 4-8: Fuel System lessons-learnt Excel Spreadsheet

4. **Maintenance:** The knowledge stream owners are responsible for the maintenance of each lessons-learnt document. They also collaboratively maintain the lesson learnt spreadsheet.

At the time of study, there were a total of 30 knowledge streams covering critical knowledge area from technical topics such as fuel mechanic to non-technical topics such as project management. In addition to the 451 lessons-learnt captured in the A350 programme, there were a total of about 900 lessons-learnt captured.

4.4.3 Context Related Issues for Lessons-Learnt Capturing and Reuse in Airbus

In subsections 4.4.1 and 4.4.2, practices to capture and reuse lessons-learnt were presented, firstly with corporate process and tool, and then with domain practice in Fuel System. In this subsection, context related issues from these lessons-learnt practices are summarised.

An overview of these issues is provided in Table 4-5 below. These issues are identified from the following source: firstly, document study was carried on excising internal report regarding lessons-learnt usage in the UK (Airbus S.A.S, 2008). Secondly, key points generated from the second workshops with Fuel System domain knowledge management (FS KM) team, as shown in Appendix C-3. Thirdly, the author took part in two RISE technical reviews meeting with Airbus Knowledge Management (Airbus KM) department[8]. In Table 4-5, specific source from which each issue was identified is indicated in corresponding columns.

Issues	Internal Study	FS KM	Airbus KM
Usage of lessons-learnt document	✓	✓	
Flexibility to define and edit contextual information		✓	✓
Connection between related information	✓	✓	✓

[8] Key points are extracted from two RISE Quarterly Technical Review presentations in 2011, in each technical review session, technical issues and users feedback for the RISE system were discussed.

Context about accessibility and permission		✓	
Information summary			✓

Table 4-5: Context related issues for lessons-learnt practices in Airbus

As shown in the above table, a total of 5 contexts related issues were identified. These are discussed in detail in the following:

- **Usage of lessons-learnt document:** According the to internal study on lessons-learnt usage, at the time of the study (2008), there was poor visibility on how lessons-learnt document were used in key engineering activity such as requirement reviews and design reviews. This issue was not entirely information system related since it was concluded that not enough priority was given to lessons-learnt usage in engineering activity. However, it was mentioned that there was very limited option on the RISE system to indicate how lessons-learnt document was used. Additionally, it was not possible to view usage related indicators of individual lessons-learnt documents (such as number of view and user browsing record). Within Fuel System, at the time of this case study there was no systematic mechanism in place to track the allocation and usage of lessons-learnt document. Such usage information was captured as action items in minutes of lessons-learnt review meeting. These meeting minutes was kept separately and was not linked to the lessons-learnt spreadsheet or related lessons-learnt documents. For this reason, although the lessons-learnt documents can be easily retrieved via the lessons-learnt spreadsheet, their usage records couldn't be easily accessed.

- **Flexibility to define and edit contextual information:** When commented upon the potential usage of RISE for Fuel System lessons-learnt, members of Fuel System knowledge management team mentioned that one of the key advantage of using their domain specific practices was that they can define what contextual information to be captured in their lesson learnt spreadsheet and document template. They can also have the flexibility to make agile edit to such contextual information when needed. A similar point was mentioned during technical review on the RISE system. User feedback for the RISE system highlighted that more flexibility was preferred to edit contextual information related to lessons-learnt document on this system.

- **Connection between related information:** According to the internal study on lessons-learnt usage, some of the lessons-learnt were created to capture top priority engineering issues, and were directly linked with aircraft requirements. Aircraft requirements were captured and managed in a separate repository, at the time of study, the connection between lessons-learnt document and requirements need to be managed manually. This was considered to be a labour intensive process, since both lessons-learnt documents and aircraft requirements were subjected to regular reviewed and changes. In the Fuel System, it was mentioned that the connection between lessons-learnt documents with other knowledge related information need be better managed. One of such example is that of best practices, as mentioned in subsection 4.4.2, the lessons-learnt review meetings often also include identification of applicable best engineering practices. Such best practices information was kept in a separate repository without connection to lessons-learnt document. These different types of information content were often inter-related and it would be beneficial to take this inter-relationship into account during engineering design. However, it was difficult to capture these relationships using existing information tools.

- **Context about accessibility and permission:** lessons-learnt are knowledge intensive engineering information. To ensure authority of such information, rigorous controls are often required during the creation workflow and also during the reuse cycle. For Fuel System, different accessibility to the same document was often required for different engineers (e.g. knowledge stream owner vs. normal engineer) at different stages (e.g. proposal vs. approval vs. reuse). There was also concerned expressed about controlling accessibility and permission with regarding to extended enterprise. The current IT facilities lacked intelligent control over such variety in accessibility and permission.

- **Information summary:** During the RISE technical review meetings, it was mentioned that the capability to provide information summary before opening lessons-learnt documents for detailed reading would be beneficial. It was highlighted in user feedback that the level of details contained in existing lessons-learnt documents varied greatly. At the time of study, users needed to open lessons leant document and sometime open individual attachment in the document to evaluate its usefulness.

This list of context related issues were main outcome of the case study on Airbus practice to capture and reuse lessons-learnt. This will be discussed and consolidated in Section 4.5 with the context related issues identified in the first case study presented in Section 4.3.

4.5 Discussion

In Wing ISS, the main objective of capturing repair experience with repair case documents was to speed up day-to-day engineering repair tasks. This practice also allowed novice engineers to learn quickly by following previous examples. Each repair case document essentially provided a "complete picture" of the handling of a past daily in-service query (ISQ), and was created via a well established process of carefully assembling different information elements together.

Compare to Wing ISS's practice, lessons-learnt practice were widely used by different departments in Airbus. It was however apparent each department followed different approach despite corporate process and tool (RISE) were in place. In Fuel System, the lessons-learnt practice contributed to evidence for design review at product development milestones. The reuse of lessons-learnt was not for daily engineering task since design reviews for different milestones would be many months apart. The lessons-learnt documents were allocated to engineers within the Fuel System department to follow up. They were also shared with other communities within the organization.

Throughout the information life cycle, the creation, storage, retrieval and maintenance of repair case documents were closely supervised by a domain expert dedicated to the process. This was different to the collaborative manner adopted by the Fuel System knowledge stream owners. The reason was that knowledge domains related to fuel systems covers a wide range of technical topics – it was difficult to have someone with all-around technical knowledge. Due to the shear volume of repair case documents, the folder/file structures used to allocate these documents were significantly more complex than that of Fuel System for lessons-learnt documents. For Wing ISS engineers, direct access to these documents via corporate file/folders system was not viable – engineers would have to manually navigate large number of folders and subfolders to get to any given repair case document.

Despite the difference mentioned above, from two aspects, both departments adopted similar approaches to organise their information:

- *Usage of a prescribed structural layer to support retrieval*: Both groups dedicate significant *manual* effort to set up a retrieval facility in the form of Excel. This essentially introduces a layer of structural metadata information to support the retrieval activities.
- *Usage of allocation guideline for information organisation:* Both groups follow strict allocation guideline to decide the location of each document in folder/file structure.

From an information system aspect, both departments decided to move away from organisational information systems, and dedicated resource to set up their own knowledge repository with standard office information tools. In the case of Wing In-Service support, the lack of integrated information source created barrier for information to be gather in a contextual manner, while the high cost of developing dedicated system prohibited developing a dedicated information system for repair specific task. In the case of Fuel System, although an organisational tool was available for lessons-learnt, it was considered to be too rigid in defining and editing contextual information, and not providing enough support for accessibility and permission control.

4.6 Summary

After the case studies, a set of context related issues were identified from each case study. These are consolidated and presented in Table 4-6 below for an overview:

Issues	Context Related Issues	Case Study
Issue 1	Support of domain semantic	Repair experience
Issue 2	Connection between related information	Repair experience Lessons-learnt
Issue 3	Information usage	Repair experience Lessons-learnt
Issue 4	Taking historical context into account	Repair experience
Issue 5	Information summary	Repair experience Lessons-learnt
Issue 6	flexibility to define and edit contextual information	lessons-learnt
Issue 7	Context about accessibility and permission	lessons-learnt

Table 4-6: Context related issues identified from the two case studies

Despite the different nature of the information and varying requirements of usage, engineers from both Wing ISS and Fuel System indicates issues that require *more intelligent* approach to leverage context. Each of the issues outlined in Table 4-6 points to specific requirement for a context aware system to support industrial practices to capture and reuse knowledge:

- *Issue 1* indicates the requirement to capture and utilise domain semantic context.
- *Issue 2* indicates the requirement to provide efficient navigation between related set of information.
- *Issue 3* indicates the requirement to capture and utilise information usage.
- *Issue 4* indicates the requirement to understand change of information value across time.
- *Issue 5* indicates the requirement to provide information summary to facilitate understanding of information content.
- *Issue 6* indicates the requirement for a user friendly approach to capture context.
- *Issue 7* indicates the requirement to take user identity into account.

Additionally, both engineering practices followed strict information organisation processes and use traditional office information applications. This indicates that, to achieve any *sustainable* improvement, the proposed solution needs to consider how to integrate with existing engineering practices and infrastructure.

Therefore based on the two case studies, it is possible to establish the following list of "context requirements" for an ideal context aware system to support knowledge work in the aerospace industry:

ID	Requirements
R1	Capture and utilise domain semantics
R2	Efficient navigation between related set of information
R3	Capturing and utilise information usage
R4	Understand change of information value across time
R5	Provide information summary to facilitate understanding of information content
R6	A user friendly approach to capture context
R7	Take user identity into account
R8	Integration with existing process and infrastructure

Table 4-7: List of context requirements

The case studies presented in this chapter allowed the author to understand, from the perspective of engineering practices, how engineering experience were captured a reused, and how the related information tasks were facilitated and performed. The set of context requirements for an ideal context aware system, as outlined in Table 4-8 above, in additional to engineering practices that were described, contribute to the scoping of further investigation in the experiment phase, as described in Chapter 5. Furthermore, as presented from Chapters 6 to 9, the repair case document search activity from Wing ISS was chosen as the engineering use case for 1) application of experimental context capturing approach; and 2) development and deployment of a context aware system for repair case document search.

5 Synthesis and Scoping

During the past decade, a large amount of research works has been conducted to investigate the development and application of context aware systems, as discussed in Chapters 2 and 3. These works covered a wide range of topics including conceptual definitions, system architecture, various technical approaches, and so on. Additionally, a significant number of systems have been developed from research and commercial settings.

Despite this relatively large number of previously developed systems, as seen Chapter 3 and Appendix A, there seems to be little application of context aware systems in the aerospace domain beyond some experimental and research systems. It is thus apparent that the capturing and utilisation of context largely remains manual and is based on standard office information tools, as discussed in Chapter 4.

This chapter presents discussion to bring together the key findings from the previous Chapters. By summarising and synthesising these key findings, as presented in Section 5.1, the technical scope for the experiment phase of this research was confirmed, key research topics for on-going investigation was fully developed, practical concerns was understood and realised. As this research project progressed from the investigation phase to the experiment phase, the research objectives were reviewed and reappraised in relation to the key findings from the investigation phase. As a result, two new research objectives were added for the experiment phase in Section 5.2. A review of the research planned is then presented in Section 5.3.

5.1 Key Finding Synthesis of the Investigation Phase

The complete list of key findings and conclusions from previous chapters are collectively illustrated in Tables 5-1 to 5-3. These can be summarised as research issues, research gaps and context requirements. In Table 5-1, **I1** to **I5** are research issues identified from existing literature that are related to industrial application of context aware system. This will be referred as "research issues" in this chapter. In Table 5-2, **G1** to **G6** are potential gaps in existing research and development of context aware systems. In the following text, these will be referred as "research gaps". In Table 5-3, **R1** to **R8** are context requirements for an ideal context aware system to support knowledge work in the aerospace. In the following text, this will be referred to as "context requirements".

ID	Research Issues
I1	Integration with existing systems
I2	Effort to capture context
I3	Demonstration of benefit
I4	Transparency to users
I5	Reusability of captured context

Table 5-1: Research issues related to industrial application of context aware systems, as shown in Chapter 2, Section 2.5

ID	Research and Development Gaps
G1	Application of semantic techniques to capture aerospace context in an integrated and open manner

G2	Effective approaches to capture semantic context
G3	Systematic combination of context aware techniques and system applications
G4	In-depth context capturing of specific engineering domain
G5	Demonstration of proposed benefits of context aware systems in operational setting

Table 5-2 Research and developments gaps, as shown in Chapter 3, Section 3.5

ID	Context Requirements
R1	Capture and utilise domain semantics
R2	Efficient navigation between related set of information
R3	Capturing and utilise information usage
R4	Understand change of information value across time
R5	Provide information summary to facilitate understanding of information content
R6	A user friendly approach to capture context
R7	Take user identity into account
R8	Integration with existing process and infrastructure

Table 5-3 Context requirements, as shown in Chapter 4, Section 4.6

By considering these research issues, research gaps and context requirements, the following elements for the next phase of this research − the experiment phase − can be defined: The technical scope, research topics for further investigation, and practical consideration. These are presented in subsections 5.1.1, 5.1.2 and 5.1.3 respectively.

5.1.1 Technical Scope of further Investigation

From a technical perspective, two inter-related points emerged from the research issues, research gaps and context requirements listed from Tables 5-1 to 5-3. The first is that of semantic context, and in particular domain semantic context: **G1** concerns application of semantic techniques to capture context in aerospace domain in an integrated and open manner, so that other related research and development initiative can build on each other's context capturing results as indicated by **I5**, while **R1** highlights the importance of domain semantics to knowledge work.

Related to this is that of context capturing: **I2** and **G2** points to the need of effective context capturing approaches. **R6** highlights the requirement for a user friendly approach for context capturing which is in turn related to the research issue of user transparency as pointed out in **I4.** As discussed in the literature review in Chapter 2, and also shown in the reviewed systems in Appendix A, context capturing activities are mostly enabled by information systems that utilise semantic representation. XML based context modelling scheme such as RDF and Ontology were widely featured in the reviewed systems. Such semantic techniques were applied to captured information semantic, but were also applied in combination with data mining and profiling techniques to provide greater level of intelligence.

Additionally, as discussed in subsection 5.1.3 below, one of the key research topics for further investigation was to demonstrate the benefits of context aware system in operational settings. This can only be achieved if context is captured and then utilised. For this reason, utilisation of captured context is also part of the technical scope.

Based on the above discussion, in the experiment phase of this research project, the technical scope of the experiment was to investigate the application of semantic technique to capture and utilise domain context.

5.1.2 Key Research Topics for further Investigation

Based on the research issues, research gaps and context requirements outlined in Tables 5-1 to 5-3, three research topics were identified for further investigation in this research. These are:

- Detailed examination of domain semantic context
- A cost-effective approach to capture domain context
- Demonstration of benefit in operational setting

The rationale for identifying these as key research topics are presented in the following text.

Detailed examination of domain semantic context

The requirement for an ideal context aware system to support domain semantics was highlighted in the context requirement **R1**. It had also been highlighted by the research gap **G4** that there was no previously research work in the aerospace to perform in-depth context capturing of specific engineering domain. Without in-depth capturing of domain semantic context, it would be difficult to provide the capabilities that would fulfil the context requirement **R1**. Moreover, little work had been performed to understand specific requirements for context capturing for specific engineering domains and in an operational setting.

In order to overcome this challenge, a more detailed examination on the nature of domain semantic context was required. This was to understand questions such as how much semantic context needs to be captured to support specific tasks such as aircraft wing repair or fuel system design.

The industrial setting of this project provided an important opportunity to contribute towards this knowledge gap. By working closely with the engineers who take part in specific aerospace knowledge work, it was possible to structure the experimental research in a way that enables the capturing and studying of engineering domain semantic context.

A Cost-effective approach to capture domain context

The research issue **I2** indicated the need to address the effort required to perform context capturing. Similarly, the research gap **G2** indicated a research gap about effective approaches to capture semantic context. For context aware systems that apply semantic techniques, the context capturing activity often involved the specification of concepts, the relationship between concepts, and the specific logic for inference. This was often enabled by specialist context modelling tool such as Protégé (Stanford University, 2013) to construct context model in formats such as OWL (W3C, 2007).

For projects in the public and academic domain, capturing and modelling context often relied on volunteers to provide support (Miller, Beckwith, Fellbaum, Gross, & Miller, 1990; Navigli & Ponzetto, 2010). This way of working to support context capturing is however unlikely to be sufficient for an on-going and sustainable context capturing activity within the aerospace industry. In the industrial domain, such activities require the presence of context modelling consultants and experienced end users - such as domain experts − to work together at length to create, review and maintain the resultant context model. These are often lengthy process requiring multiple iterations, and are therefore expensive (Gruninger & Lee, 2002) for business departments in term of human capital and time.

Therefore, this important issue hinders attempts to capture context in engineering domain over a sustained period. Consequently, this topic had a significant impact on the research aim of this project which was to investigate the application of context aware systems in the aerospace industry. For this reason, it was essential to investigate a context capturing approaches that would be more cost-effective and more likely to be adopted by industrial practices.

Demonstration of benefits in operational setting
As highlighted in research gap **G5,** and also in research issue **I3**, more research need to be done to understand and demonstrate the benefit of context aware systems. Although many authors had written about application of context aware systems for strategic competitive advantages, such as enabling better knowledge management practices in corporate (Schmidt, 2005; Abecker, Bernardi, Hinkelmann, Ku, & Sintek, 2000), there was however very little specific measurable evidence of operational or financial benefit.

Few systems surveyed in the state of the art study, as discussed in Chapter 3, were used in operational setting. On the other hand, without wider deployment, it remained difficult to elaborate use cases with high fidelity, and then to evaluate specific benefits that context aware systems can bring to engineering domains within industry.

Given this interdependency between operational application and benefit demonstration, it is an opportunity for this research project to work closely with business department in Airbus. This would allow a new use case to be developed and deployed within a real-life engineering setting for sustained period. This can in turn allow various aspects of the implementation to be reviewed, refined, and evaluated in the business context.

5.1.3 Practical Considerations

The research issues, research gaps and context aware requirements, as outlined from Tables 5-1 to 5-3, also pointed to topics that need to be considered during the technical implementation of context aware systems. These are listed in the following:

- A user friendly approach to capture context, as pointed out by the context requirement **R7**.
- Reusability of captured context, as pointed out by the research issue **I2** and the research gap **G1**.
- Integration with existing systems, as pointed out by the research issue **I1** and the context requirement **R8.**

These topics were not systematically investigated within this research project. However they served as guidelines which the design of the experiment and the development of the proposed systems adhere to. These are discussed in the following:

A user friendly approach to capture context:

At the time of the study, the tools used for context capturing and context model construction were typically tailored for a knowledge modelling specialist. It was not easy for knowledge workers such as domain experts to directly use these tools. This in turn hindered their ability to provide continuous improvement and validation to the captured context.

In order to allow detailed study of domain context as discussed in subsection 5.1.2, and to investigate cost-effective context capturing approach as discussed in subsection 5.1.3, it was ideal for this research project to use or develop a context capturing approach and tool that is easy for knowledge workers to use.

Reusability of captured context

Little attention had been paid to how context captured by context aware systems can be re-used for multiple purposes. For example, a semantic model used to support information search could also used to generate a domain specific glossary, while profiled domain search activity can be analysed to provide business intelligence such as understanding the information needs of certain engineering tasks.

At the time of this research, without significant additional development, such reusability was difficult to achieve with the context aware systems to date. The underlying semantic model or profiled information were lacking in both transparency to knowledge workers and support for interoperability between systems.

For this research project to demonstrate the benefit of context aware systems as mentioned in subsection 5.1.4, it is ideal that any potential captured context can be modelled in a manner that it is easily accessible. So that it can contribute to other business initiative as well as future research and development.

Integration with existing systems

Within the systems surveyed in the state of the art review, most were stand-alone systems with self-contained functionalities. From a research and development perspective, such system design allows flexibility to choose a technology platform to deliver targeted functionality. However this also creates challenges for potential adopters to integrate such systems into their daily work routines.

Instead of creating a stand-alone experimental solution, this project had the opportunity to focus on developing contextual aware capability embedded in standard information tools such as the ones used in the engineering practices in the case studies. These information tools allowed flexibility to create plug-in functions for the development of certain experimental features. In addition this allowed for the flexibility, transparency and accessibility required by knowledge workers to be involved in the development and evaluation of context aware capabilities.

5.2 Review of Research Objectives

The research aim and the research objectives have been introduced in Chapter 1. This research project started the research work for the investigation phase with the two initial research objectives, repeated below:

- **Research Objective 1**: To understand the state of art in research, development and application of context aware systems.
- **Research Objective 2:** To understand the nature of context in the aerospace industry.

After the investigation phase, key findings from the main research activities investigation phase were synthesised, as presented in Section 5.1. This allowed key elements of the experiment phase to be defined, including the technical scope, research topics, and practical considerations for further investigation.

Consequently, the initial set of research objectives are revised to reflect the research direction taken in the experiment phase. The discussion explaining the development of each research objective is presented in subsections 5.2.1, 5.2.2 and 5.2.3. The results of this revision and the developed research objectives are presented in subsection 5.2.4.

5.2.1 Review of Research Objective 1

Research objective 1 was to understand the state of art in research, development and application of context aware systems. Research activities contributed to this objective included:

- The literature review as discussed in Chapter 2
- The state of the art review as discussed in Chapter 3

From the literature review, a classification of context and a classification of context aware techniques were defined, five types of applications provided by existing context aware systems to support knowledge work were reviewed, and a list of research issue related to industrial application of context aware systems were identified.

The classification of context aware techniques and the five types of applications were used to as system dimensions for system evaluation in the state of the art review. This review included the review of 73 systems, as seen in Chapter 3 and Appendix A, from four system dimensions. The state of the art review resulted in the identification of potential gaps in the research and development of context aware systems.

The list of research activities and corresponding outputs that contributed to this research objective is shown in Table 5-4. After the investigation phase, research objectives 1 was considered to be achieved.

Research Objective	Research Activities (Chapter) - Contributing Outputs
RO1: **To understand the state of art in research, development and application of context aware systems in academic, public and industrial domains.**	Literature review on related research areas (Chapter 2) - Classification of context - Classification of context aware technique - Applications provided by existing context aware systems - Research issues related to industrial application
	State of the art review on context aware systems (Chapter 3) - Gaps in context aware systems research and development

Table 5-4: Research activities and outputs that contributed to Research Objective 1

5.2.2 Review of Research Objective 2

Research objective 2 was to understand the nature of context in the aerospace industry. During the investigation phase, the industry case studies activity contributed to this objective. From the two industry case studies conducted, context requirements for an ideal context aware system to support knowledge work were identified, as shown in Table 5-3. This list of context requirements contributed to research objective 2, since they were related to context related issue that engineers faced while performing industrial practice to capture and reuse engineering experience.

After synthesising key findings from the investigation phrase, as discussed in Section 5.1, more scope of investigation toward this research objective was identified after the investigation phase. As mentioned in subsection 5.1.2, detailed examination of domain semantic context was identified as a key research topic for further investigation. The aim of this investigation was to understand the nature of semantic context in in domain specific engineering activities in the aerospace industry. This aim was considered as an extension of the on-going investigation toward research objective 2.

Based on this reflection, research objective 2 was to be further investigated in the experiment phase. Research activities that contributed into this research objective are discussed in subsection 5.3.1.

5.2.3 Additional Research Objectives in the Experiment Phase

As the research progressed from the investigation phase to the experiment phase, key findings from the investigation phase were synthesised. Two *new* research objectives were added in the light of the research topics identified for further investigation.

Firstly, the research topic "a cost-effective approaches to capture domain context" was identified for further investigation. This was included as a research objective in the experiment phase. For the rest of this thesis, this is referred to as "research objective 3".

Secondly, the research topic "Demonstration of benefits in operational setting" was also identified for further investigation. It is out of the scope for this research project to fully investigate or develop a systematic approach to evaluate the business value of technology system. However, it is relevant to the development of context aware systems in an operational setting and the use of empirical evidence to understand the potential impact on business activities. For this reason, the research objective "to *explore the application of* *context aware systems to support aerospace knowledge work in operational setting*” was included for consideration in the experiment phase. For the rest of this thesis, this is referred to as “research objective 4”.

Based on the above discussion, research objective 3 and research objective 4 were added for the experiment phase. Research activities that contributed into these two research objectives are discussed in subsections 5.3.2 and 5.3.3.

5.2.4 Outline of Revised Research Objectives

As discussed above, the research objectives were reviewed after the investigation phase of this research project. The main result of this revision is as the following:

- Research objective 1 was achieved.
- Research objective 2 was to be further investigated in the experiment phase.
- Research objectives 3 and 4 were added, to be investigated in the experiment phase.

The revised set of research objectives are listed as below:

- **Research Objective 1**: To understand the state of art in research, development and application of context aware systems.
- **Research Objective 2:** To understand the nature of context in the aerospace industry.
- **Research Objective 3:** To investigate a cost-effective approach to capture domain context.
- **Research Objective 4:** To explore the application of context aware systems to support aerospace knowledge work in operational settings.

5.3 Research Plan for Experiment Phase

Following the revision of the research objectives, as discussed in Section 5.2, research plan for the experiment phase is presented in this section. Research activities in the experiment phase aims to achieve research objectives 2 to 4. These are discussed in the following from subsections 5.3.1 to 5.3.3. The research plan including research activities in the experiment phase are presented in subsection 5.3.4 and shown in Figure 5-1.

With reflection to the research methodology presented in Section 1.6, research activities presented in this plan belong to the “Prescriptive Study” and “Descriptive Study II” stages.

5.3.1 Research Activities for Research Objectives 2

Research objective 2 was to understand the nature of context in the aerospace industry. Specifically, in the experiment phase, research was conducted to perform detailed examination on domain semantic context used by engineers to perform their work.

To achieve this, an experiment was conducted to capture and utilise In-Service Support domain context. Two types of context were captured: semantic context and effective search terms. The capturing of domain context was achieved by performing feedback based context capturing using the Daedalus repair case search tool.

Resulted from this experiment, In-Service Support domain semantic context was captured, alongside with effective search terms, and usage data of Daedalus was also retained. Empirical study was then conducted on these experiment data. This is presented in Chapter 8.

The following Table 5-5 provides an overview of research activities that focused on the revised research objective 2, alongside with the contributing outputs.

Research Activities (Associated Chapter)	Contributing Output
Experiment to capture and utilised domain context (Chapter 8)	Experiment data including: - Captured context - Daedalus usage data
Empirical study and evaluation (Chapter 8)	Study result of experiment data

Table 5-5 Research activities and outputs contributing to Research Objective 2

5.3.2 Research Activities for Research Objective 3

Research objective 3 was to investigate a cost-effective approach to capture domain context. To achieve this, a **F**eedback **B**ased **C**ontext **C**apturing (**FBCC**) approach was proposed. This approach allowed knowledge workers to perform user-driven feedback to the captured context after initial set up sessions. This is discussed in detail in Chapter 6.

The FBCC approach formed part of the experiment designed with the In-Service Support use case. It was enabled by the development of the Daedalus repair case search tool, as discussed Chapter 6. During the experiment period, as described in Chapter 8, contextual information was captured and accumulated. This was then studied during the empirical study and evaluation activities, also described Chapter 8.

The following Table 5-6 provides an overview on research activities that contributed to the revised research objective 3, alongside with the contributing outputs.

Research Activities (Associated Chapter)	Contributing Output
Experiment Design (Chapter 6)	Feedback based context capturing approach (FBCC)
Experiment to capture and utilised domain context (Chapter 8)	Experiment data including: - Captured context - Daedalus usage data
Empirical study and evaluation (Chapter 9)	Evaluation of FBCC approach

Table 5-6 Research activities and outputs contributing to research Objective 3

5.3.3 Research Activities for Research Objective 4

Research objective 4 was to explore the application of context aware systems to support aerospace knowledge work in operational setting. To achieve this objective, the repair case search tool Daedalus was developed and deployed during experiment phase. It was designed as a simple repair case search tool for repair engineers to perform their daily repair case search activities by following the Wing ISS ISQ process discussed in Chapter 4.

The core functionalities of Daedalus was conceptualised as part of the experiment design for capturing and utilising domain context, as described in Chapter 6. These core functionalities was then implemented during the system development activities, as described in Chapter 7. During the experiment period, system usage data of Daedalus were captured. This allowed for the evaluation of the impact of Daedalus on the In-Service engineering activities, as discussed in Chapter 8.

The following Table 5-6 provides an overview on research activities that contributed to the revised research objective 4, alongside with the contributing outputs.

Research Activities (Associated Chapter)	Contributing Output
Experiment Design (Chapter 6)	Conceptualisation of Daedalus
System Development (Chapter 7)	Implementation of Daedalus
Experiment to capture and utilised domain context (Chapter 8)	Daedalus usage data
Empirical study and evaluation (Chapter 8)	Evaluation of system impact on In-Service activity

Table 5-7 Research activities and outputs contributing to Research Objective 4

5.3.4 Research Plan for the Experiment phase

The research plan for the experiment phase is presented in Figure 5-1 below. This includes the research activities planned to achieve research objectives 2, 3 and 4, as outlined from subsections 5.3.1 to 5.3.4. Also shown are the key outcomes from each activity contributing the research objectives.

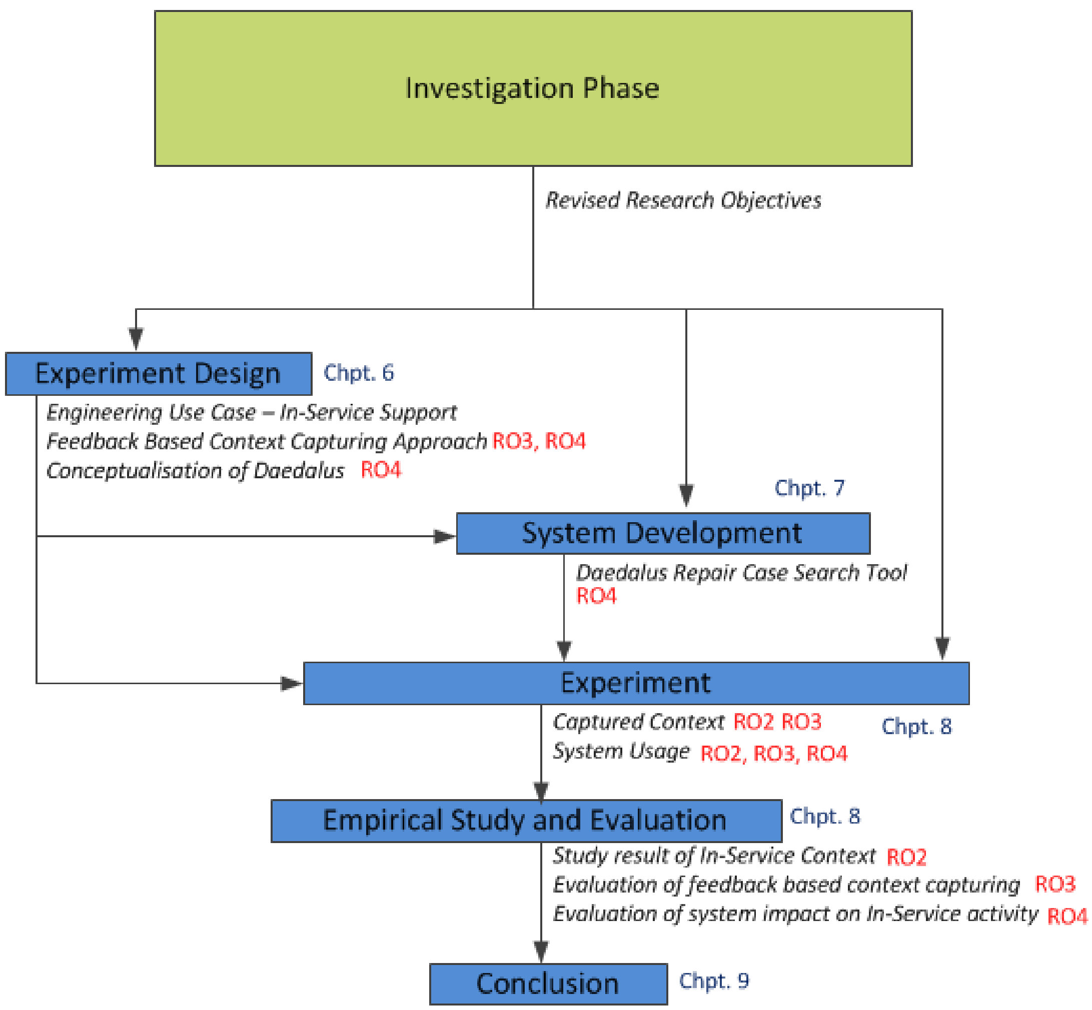


Figure 5-1 Research plan for the experiment phase

5.4 Summary

After the investigation phase, key findings from different research activities in this phase were analysed. This is presented in Section 5.1. Resulting from this analysis, the following elements of the experiment phase were identified:

- Technical scope for research work in the experiment phase.
- Key research topics to be further investigated
- Practical considerations for experiment design and system development.

As described in Section 5.2, the research objectives were then reviewed in the light of research activities conducted. After the review, research objectives 1 was considered to be achieved, research objective 2 were to be further investigated, and finally research objectives 3 and 4 were added. The revised set of research objectives are listed as below

- **Research Objective 1**: To understand the state of art in research, development and application of context aware systems.
- **Research Objective 2:** To understand the nature of context in the aerospace industry.
- **Research Objective 3:** To investigate a cost-effective approach to capture domain context.
- **Research Objective 4:** To explore the application of context aware systems to support aerospace knowledge work in operational settings.

The research plan for the experiment phase was then presented in Section 5.3. For each research objective to be investigated in the experiment phase, research activities and respective outcomes were identified.

6 An Experiment to Capture and Utilise Context of Aerospace Knowledge Work

After key findings in the investigation phase were synthesised, as described Chapter 5, the research objectives were revised. The technical scope of the experiment phase was identified alongside with practical consideration regarding the industrial context of this research. Starting in Chapter 6, the discussion moves on to research activities in the experiment phase.

In the experiment phase, research activities started with the design of an experiment for context capturing and utilisation in an aerospace setting. This served as a starting point for subsequent activities in system development, deployment and research evaluation. Various elements of this experiment are discussed in this Chapter.

This chapter starts with discussions about the purpose and deliverables of the experiment in Section 6.1, and the scope in Section 6.2. An overall view of FBCC - a Feedback Based Context Capturing approach is then presented in Section 6.3. For FBCC and its experimental application to fulfil its purpose in both research and business perspective, the experiment need to carried out in an appropriate organisational setup and with clear defined use case. This organisational setup is introduced in Section 6.4, while the use case setup is introduced in Section 6.5. An experiment was developed and deployed within the Wing ISS domain to provide context awareness capability during repair case search activity. The overall validation method of FBCC is introduced in Section 6.6.

6.1 Experiment Purpose and Deliverables

As discussed 5.3, after the investigation phase, three research objectives remained to be fulfilled. These are listed below:

- **Research Objective 2:** To understand the nature of context in the aerospace industry.
- **Research Objective 3:** To investigate a cost-effective approach to capture domain context.
- **Research Objective 4:** To explore the application of context aware systems to support aerospace knowledge work in operational settings.

The purpose of this experiment was *to conduct research activities to fulfil these three research objectives.* In order to achieve this, the results of this experiment need to obtain the deliverables shown in Table 6-1 below:

Research Objective	Required Experiment Deliverables
Research Objective 2	Domain semantic context from aerospace engineering domain to be captured and then studied
Research Objective 3	An approach for capturing domain context to be proposed, applied

	and then evaluated
Research Objective 4	1. A context aware systems to be developed and applied to support knowledge work in operational setting 2. The system to be evaluated with regards to the level of adoption and impact on knowledge work.

Table 6-1: Research Objectives vs. Required Experiment Deliverables

Among the deliverables shown, an approach for capturing domain context was of high priority. Without such a mechanism to capture context, it would have been difficult to capture domain context to the granularity required for detailed study. Meanwhile, it was obvious that without capturing context, a context aware system could not be developed to utilise such context to support knowledge work. It was based on these considerations that a **F**eedback **B**ased **C**ontext **C**apturing (**FBCC**) approach was proposed. The overall design of this approach is presented in Section 6.3, while its application in the Wing ISS engineering use case is introduced in in Section 6.4. However it is first necessary to scope the experiment.

6.2 Experiment Scope

In the frame of this experiment, the type of knowledge work involved is engineering repair design taking place in the aerospace industry. While the knowledge workers involved are domain experts or engineers from the collaborating engineering department.

The nature of the aerospace engineering work associated with this research is predominantly information processing work conducted by engineers using various systems on networked desktop or laptop computers, as described in Section 4.3 For this reason, the type of context that was addressed in the experiment phase was the contextual information that, if captured, can be used to support engineers to perform this information work. This will be further addressed in Section 6.5.

From a technical point of view, as mentioned in the Section 5.1, the scope of this experiment was to apply semantic technique to capture and utilise domain context. Daedalus - the resulted context aware system utilise the captured context to provided information search and information push. These will be further addressed firstly in Section 6.5, and then in Chapter 7. It is worth noting that, although it was essential for the intended context aware system to feature context utilisation capabilities, it was not in the scope of this research to investigate advanced techniques for context utilisation.

6.3 Overview of FBCC – Feedback Based Context Capturing

In this section, the overall design of a **F**eedback **B**ased **C**ontext **C**apturing approach (**FBCC**) is outlined. The rational of this approach is discussed in subsection 6.3.1. The outline of FBCC is presented in subsection 6.3.2. Finally, practical consideration regarding the application of FBCC is addressed in subsection 6.3.3.

6.3.1 Rationale for a Feedback Based Context Capturing Approach

As mentioned in Section 5.1, context capturing approach applied in existing research and development often feature lengthy context capturing and modelling processes. In the industry domain, such approaches would require significant contribution from domain experts and are therefore expensive for business departments in term of human capital and time.

From a research perspective, two key elements were identified by Warren (2006) for more cost-effective approaches: 1) Developing semi-automatic tools for learning ontologies and extracting metadata; and 2) Generating metadata while performing business tasks. The FBCC approach proposed and created for this research can be related to both of these elements: It encourages knowledge worker to perform context capturing as they undertake their daily activities, so that the underlying context model can be continuously improved by user feedback. Instead of the semi-automatic approach that is recommended by Warren, a manual approach was provided with significant level of transparency given to the user.

From a business operation perspective, a key rationale of such a feedback based approach was the observation that "information curators" are often put in place to ensure information quality and reusability (Lee, Tibbo, & Schaefer, 2007). In the industrial cases studies presented in Chapter 4, both departments participated in the studies had to appoint domain experts to perform curation tasks on repair cases information and lessons-learnt. These "information curators" were the ideal candidate for knowledge workers who could be involved in the on-going process to capture domain context and provide consistent feedback. As evident from discussion in Chapter 8, it can observe that the contribution from the collaborating repair case curator was significant for the experiment.

Within the scope of this research project, only one engineering use case was included in the experiment due to resource and time constrain. However, the design for both FBCC and the Daedalus system was intended for wider application. The task of context capturing could be readily be conducted by any competent engineers in any given engineering domain. It is worth pointing out that, the manual approach of FBCC does not rule out the potential benefit of a semi-automatic approach. The limitation of the manual approach is observed and discussed in Section 9.5, and that implementation of semi-automatic approach with data mining techniques is considered to be one of the potential aspects for future research and development in Section 9.6.

6.3.2 Outline of FBCC

In order to capture such context in a cost effective manner, the author proposed a three-phase context capturing activity within FBCC. These phases are: Usage Profiling, Context Setup and Context Feedback. In each of these phases, the author proposes to have different context capturing methods while keeping close involvement of engineer users. These are discussed in detailed in the following text.

Usage Profiling

First of all, the author proposes to use automatic profiling technique to profile system usage by engineering users on targeted engineering tasks, as illustrated in Figure 6-1. As described in the case study, information search terms are articulations of domain concepts and also represent the information needs of engineers. In addition user identity can be captured to integrate with personal information to provide individualised context.

Figure 6-1 FBCC – Usage Profiling Phase

By starting with this automatic method, it is possible to profile significant amount of usage data without much involvement of engineers. Information such as search terms would collectively provide an overall description of the contextual information used in the engineering domain. This data therefore can be used to establish initial version of context model, as further discussed in subsection 6.5.2.

Context Setup

In the *Context Setup* phase, the author proposes to work with information curators in a consultative manner to setup an initial context model of the target engineering domain. This context model shall consist of elements that represent contextual information used by engineers during the targeted engineering task. The generic context capturing process in this phase is described in the following, and illustrated in Figure 6-2:

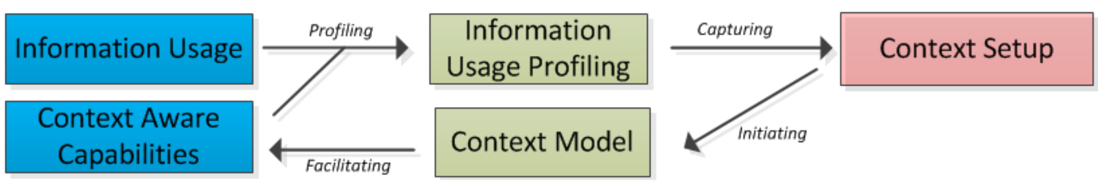


Figure 6-2 FBCC – Context Setup Phase

1. Usage data are profiled as described in Fig 6.1
2. Contextual information is captured by studying the usage data captured in the Initial *Usage Profiling* phase. Such contextual information can also be captured by letting information curator and any other participating engineers to reflect on their engineering experience.
3. The author and the information curator work together to create an initial version of context model. In a generic situation this activity would be initiated and accomplished by engineers who are trained.
4. After this phase, the proposed context aware functionalities will be activated to allow the captured context element to be utilised.

Context Feedback

In the *Context Feedback* phase, the author proposes that the context capturing activity is driven by feedback from the information curator in the targeted engineering activity, as illustrated in the Figure 6-3.

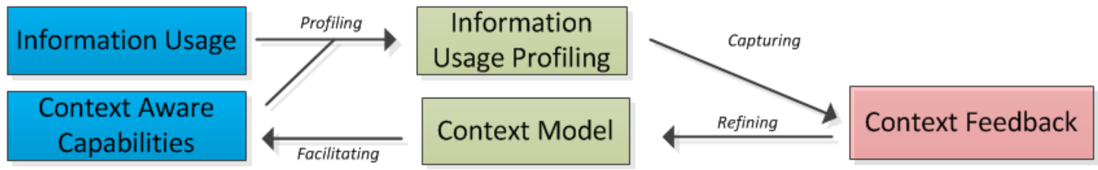


Figure 6-3 FBCC – Context Feedback Phase

During this phase, the main difference compared to the Context Setup phase is that the author or other knowledge modelling experts no longer takes an active role in the context capturing activities. Profiling of usage by engineers will continue. The information curators will be encouraged to keep monitoring the usage of the system, and perform feedback into the context model when potential useful contextual information is captured in the usage data.

6.3.3 Practical Considerations for Application of FBCC

As mentioned in subsection 5.1.3, there is a lack of context capturing tools appropriate for busy and pressurised knowledge workers. This is a real barrier for knowledge workers to directly perform context capturing, as well provide improvement and validation to the captured context. In order to enable the experimental application of FBCC, the experiment needed to provide a mechanism for domain experts and engineers who take part in the engineering use case to capture this context efficiently. The overall design of this mechanism is presented in Section 6.5, while the actual development activities are presented in Chapter 7.

6.4 Organisational Setup of the Experiment

As mentioned in Section 6.1, a key deliverable of the experiment is the development and application of context aware system in operational setting. For this proposed context aware system to deliver actual benefit to the engineering activity, the organisational factors of this experiment needed to be addressed, as well as the engineering use case which the experiment was based on. These are discussed in Sections 6.4 and 6.5 respectively.

It was decided that the experiment was to take place in the domain of Wing ISS, as mentioned previously. Additionally, repair cases search was selected as the engineering use case. In-service engineers from both design and stress disciplines were to be the users of the proposed context aware system, while the repair cases curator would perform context capturing as well as provide feedback to improve the captured context. Rationale for this organisational setup is provided in detailed in subsections 6.4.1, 6.4.2 and 6.4.3.

6.4.1 Selection of Engineering Domain

The industrial case studies presented in Chapter 4 provided a good base to identify potential use case for application of context aware systems in aerospace engineering practices. Both the lessons-learnt and repair experience capturing practices were well established within respective engineering department. In the other hands, engineers working on both engineering practices had identified that more intelligent approach to support information handling as a promising improvement area.

At the time of study, a corporate Lessons-Learnt tool was in place to facilitate capturing and reuse of lessons-learnt. This tool was deployed as the central repository to help create and share lessons-learnt information in the company. Compare to this, there was no such facility on the corporate level to capture repair experience in the foreseeable future. For this reason, it was considered that the technical work of this experiment can contribute more to the Wing ISS community. In addition the ways of working and dealing with in-service information were deemed comparatively more stable, and there was a clear need to investigate better approaches to deal with this type of information. Also at the time of this research, the Wing ISS was setting up new operational team in the U.S. In-Service engineers in the USA didn't have close association with experienced colleagues in the UK, and better way to curate and search in-service repair cases were being viewed as a high priority.

Additionally, as introduced in the industrial case study in Section 4.3, In-Service engineers were under considerable pressure to deliver engineering solution in short deadline. Therefore the in-service engineering population in general were open to explore better way to deal with their engineering information. Based on this, the Wing ISS domain was chosen as the engineering domain to for the experiment to capture and utilise context.

6.4.2 Selection of Engineering Activity as Engineering Use Case

Among various engineering activities within the remit of the in-service domain, the process of daily ISQ (In-Service Query) relied heavily on reuse of knowledge due to the strong time constraint. Within this engineering process, it was decided that the repair cases search activity had most potential to be the use case for this experiment. As mentioned in Section 4.3, this repair case search activity allows engineer to locate past repair cases that are similar to the task at hand.

The process to organise repair cases to support the repair case search activity was well established throughout the lifecycle of repair cases information e.g. repair cases creation, organisation, search and usage. This provided the ideal opportunity to capture context and also monitor the usage of captured context.

This repair case search activity made use of basic office information tools such as Microsoft Excel and typical file/folder systems to facilitate the information creation, organisation and retrieval. This provided the opportunity to develop the proposed context aware system in a manner that is integrated with such standard office information tool.

Base on above discussion, the use case of the experiment is to use a context aware system support repair case search by enabling the following:

- The application of FBCC to capture in-service support context
- The utilisation of the captured context by providing application with context aware capabilities. These will be further discussed in Section 6.5.

6.4.3 Engineering Users

A repair case curator was identified and invited to perform user-driven context capturing, and provide feedback to the proposed solution. The repair case curator had a well defined role to gather repair case information from engineers, provide quality control, and making sure availability of repair cases.

In-Service engineers were to be the main users of the proposed context aware system. They would be using this system to perform repair case search. Through out the experiment period, their usage of the proposed context aware systems would be profiled and studied.

6.5 Engineering Use Case of the Experiment

The organisational setup of the experiment has been discussed in Section 6.4. This organisational setup allowed the experiment to be positioned with regards to engineering domain, targeted engineering activity and engineering users.

The overall engineering use case is described in this section. This use case setup provided overall details about how the experiment was implemented. This include a discussion on what context about the Wing ISS domain were to be captured, the context aware capability to be developed in the frame of this experiment, and how FBCC would be applied for context capturing. These are covered respectively in subsections 6.5.1 and 6.5.3

6.5.1 In-Service Support Context

In the industrial case study, domain semantics were proposed as a key type of context that was important to In-Service engineering activity. It was revealed that the lack for support to deal with related terms such as synonyms and acronyms resulted in inconsistent repair case search results. This created barriers for in-service engineers to see the complete set of repair cases that were related to his/her information need, contributing to prolonged search time, inconsistent selection of repair solution and even unnecessary repeat work of existing repair solution.

Additionally, in the Wing ISS case study, it was highlighted that there was a need to see "what other people are searching" so that search terms that lead to effective search results can be shared among engineers.

Based on above discussion, it was decided that two types of contextual information to be captured were semantic context and "effective search term". Detailed of these are given in the following:

Semantic Context:

This is contextual information that can be regards as part of the domain semantic used in the in-service engineering tasks. In the experiment, this was further divided into the following

- *Concepts*: These are key concepts used within the Wing ISS repair domain
- *Relationships*: These are terms considered to have semantic relationship with a given concepts. Two type of relationships were to be captured:
    - Synonym /Acronym: Terms that are of same semantic meaning to another term in the form of synonym or acronym. For example, "Aileron" is the synonym of ATA part number "57-61-21"; "MLG" is the acronym of "Main Landing Gear"

- Hyponym: Terms that refer to semantic meaning included within that of another term. For example "Rib 1" is a hyponym of "Rib"

Effective Search Terms

It was decided that the search activity of engineers was captured as "*effective search term".* The term "effective search terms" refer to a collection of search terms that were used commonly within the Wing ISS engineering population, and can lead to effective search results. Such search terms can be regarded as "best practices" for engineer to construct their search queries while searching for repair cases.

In order to capture these two type of contextual information, search terms used by in-service engineers while searching for repair cases were profiled throughout three phases of FBCC's context capturing activity as described in Section 6.4. Additionally, the repair case curator regularly examined these search terms to extract key in-service domain concepts and effective search terms. The implementation of experiment to enable these context capturing activities is presented in detail in Chapter 7.

6.5.2 Conceptualisation of Daedalus

As mentioned in Section 6.1, a context aware system was required to enable the capturing and utilisation of context during this experiment. As a result, the system Daedalus[9] was developed.

In the frame of the selected engineering use case, Daedalus was designed to provide support to repair case search. From a system application point of view, the core functionality of Daedalus was to provide enhanced and context supported search functionality for engineers to search for repair cases. Additionally, information push was provided in the form of search terms suggestion.

The implementation of the basic search function is more related to standard development and will be covered Chapter 7. In the purpose of this experiment, the essential elements are the capabilities to utilise captured context and the capabilities to enable application of FBCC to capture context. These are discussed below.

Utilisation of Captured Context

As discussed in subsection 6.5.1, contextual information captured in the experiment was semantic context and effective search terms. In Daedalus, the following functionalities were implemented to utilise these two types for contextual information. These were search query expansion and search terms suggestions, as discussed in the following:

- *Search Terms Expansion:*
  The semantic context captured by the experiment was used to facilitate search terms expansion when engineers initiate a repair case search with a given search term. This capability allowed a given search term to be expanded according to the semantic content of the search term. Detailed implementation for this capability is presented in subsection 7.7.4.

[9] The name "Daedalus" was chosen by the in-servce engineers in the Wing In-Service Department. In Greek mythology, Daedalus was a skilul and was the inventor of Icarus's wings.

- *Search Terms Suggestion:*
  The effective search terms captured by the experiment were used to facilitate search terms suggestions. This capability allowed Daedalus to provide search terms suggestions based on what the user was typing. Detailed implementation for this capability is presented in subsection 7.7.5.

Application of FBCC in Repair Case Search

Figures 6-4, 6-5 and 6-6 illustrate how the FBCC approach was applied in the context of the engineering use case. Throughout the experiment, usage data was captured from engineers' actions while searching for repair cases, as shown in Figure 6-4.

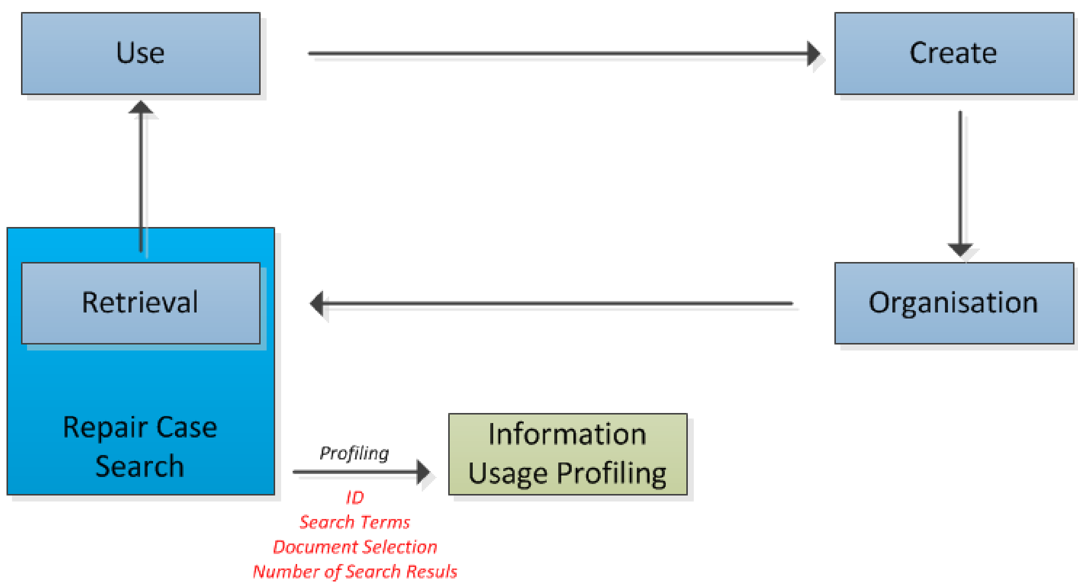


Figure 6-4 Application of FBCC – Usage Profiling phase

During the Usage Profiling phase, only the basic repair case search functionality was available Daedalus. In-service engineers were invited to use Daedalus to search repair cases that were related to their task. As they were using Daedalus, it captured information such as engineer identities, search terms used, document opening activities and number of search results. The implementation of this profiling functionality is presented in subsection 7.7.6.

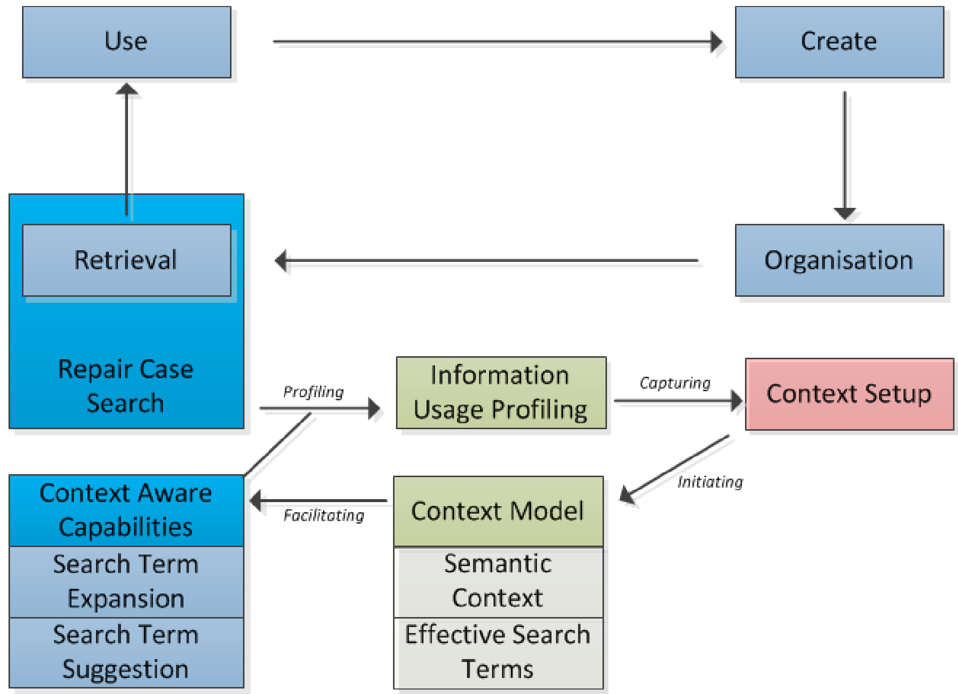


Figure 6-5 Application of FBCC – Context Setup phase

The initial context capturing activity was carried out by the repair case curator during his task to organise the repair case information as shown in Figure 6-5 and Figure 6-6. During the context setup phase, the author worked together with the repair case curator to identify key domain concepts, related terms and effective search terms, and constructed early versions of the context model. This context model was then used to facilitate the context utilisation capability in Daedalus. The implementation details of the context capturing functionality and the underlying context modelling scheme are presented in subsections 7.7.2 and 7.7.3.

In the context feedback phase, as shown in Figure 6-6, the context feedback activity was integrated as part of the repair case organisation task. During this phase, the repair case curator performed context capturing independently without the author's involvement.

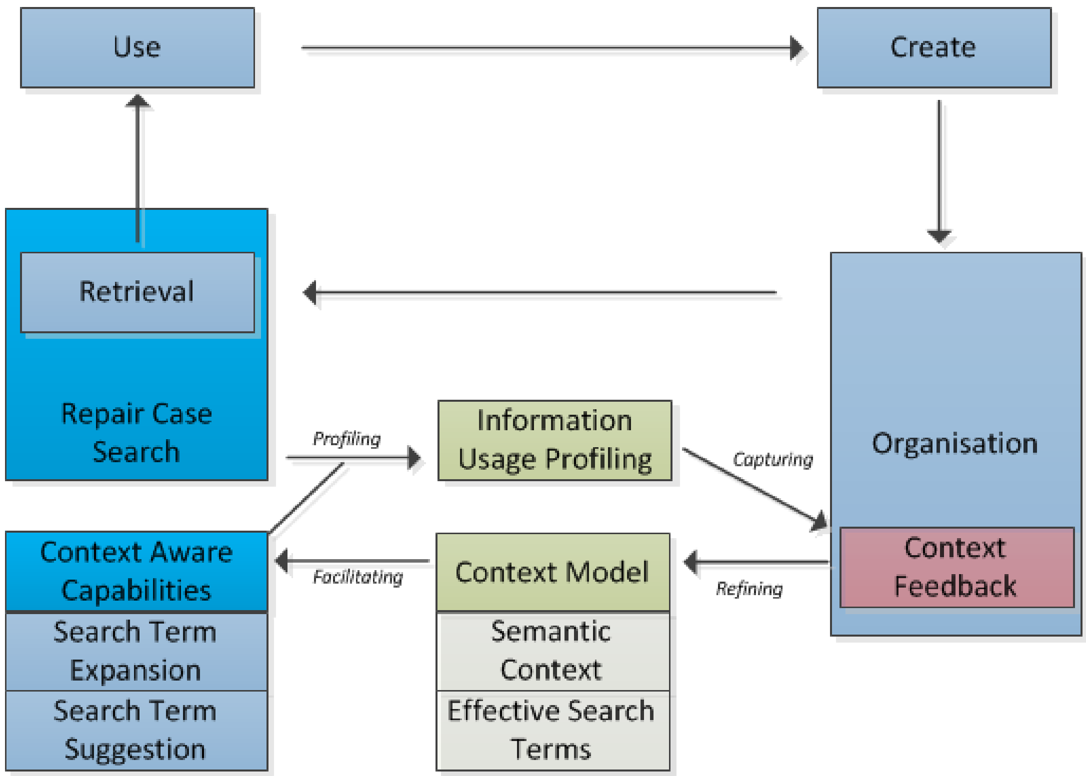


Figure 6-6: Application of FBCC – Context Feedback phase

6.6 Empirical Study and Evaluation Approaches

The purpose of the experiment was to conduct research activities to fulfil research objectives 2, 3 and 4 of this research project. Reflecting this purpose, the focus of evaluation of the experiment was the following: In-depth Examination of In-Service semantic context, evaluating the FBCC approach, and evaluating Daedalus, the context aware system. The overall empirical study and evaluation approaches for these are presented from subsections 6.6.1 to 6.6.3, with reference to the detailed discussion about evaluation results in Chapter 8.

6.6.1 In-Depth Examination of Domain Semantic Context

Throughout the experiment, usage data was captured as a result of the usage profiling activity. All search terms used by the engineers were included in this usage data. These search terms provide detailed information about domain context of Wing In-Service Support.

The examination of domain semantic context therefore was conducted by performing a serial of studies on these search term. An overview of these studies is provided in below:

- Usage distribution of search terms , this is discussed in detail in subsection 8.3.1
- Comparative study on search terms and by aircraft product categories, this is discussed in detail in subsection 8.3.2
- Comparison between Wing ISS domain concepts and Organisational generic context, this is discussed in detail in subsection 8.3.3

6.6.2 Evaluating Feedback Based Context Capturing

During the deployment period of the experiment, the repair case curator also captured domain semantic context and effective search terms in the form of context element in the context model. Meanwhile, different versions of the context model were retained for comparative study during the evaluation process.

The focus of the evaluation of FBCC was to understand its cost-effectiveness during the experiment. As mentioned in Section 6.3, the aim of FBCC was to achieve ideal cost-effectiveness by encouraging engineer users to capture context during their daily tasks with manual approach. This was evaluated in the following two perspectives: firstly by analysing the context capturing activity with reflection to examination results of In-Service Support domain context, and secondly by analysing how the captured context was utilised. In particular, the following studies were performed:

- Contribution to the context capturing activity during different stage of FBCC. This is discussed in detail in subsection 8.4.1.
- Association between captured context and top search terms. This is discussed in detail in subsection 8.4.2.
- Utilisation of semantic context with relation to the search terms used by in-service engineers during the experiment. This is discussed in detail in Section 8.5
- Utilisation of effective search terms when they were presented as search suggestions to in-service engineers during the experiment. This is discussed in detail in Section 8.6.

Finally, the justification of cost-effectiveness of FBCC came from understanding how much cost in terms of time and labour engineer users had to contribute, and in return, how effective was the context capturing and context utilisation during this experiment.

6.6.3 Evaluating Daedalus the Context Aware System

Evaluation of Daedalus was addressed by investigating the system usage from the following two perspectives: the adoption of Daedalus and the impact Daedalus on repair case search activity. These are explained in the following:

The adoption of Daedalus

The adoption of the system is evaluated by studying general usage pattern to understand the overall level of usage of the system. These are discussed in detail in subsection 8.7.1

- Usage level of repair case search by time periods
- Usage level of repair case opening by time period
- User number by disciplines and locations

Impact of Daedalus on repair case search activity

This is evaluated by comparing general usage pattern observed at beginning of the experiment to the usage pattern observed at the end of the experiment. In particular, he change in “documents opened per search” over the experiment period was studied. The detailed evaluation result for this is presented in subsection 8.7.2

6.7 Summary

During the experiment phase of this research, an experiment was conducted to capture and utilise context of aerospace knowledge work. In Chapter 6, the overall design of this experiment is presented. This was part of works that form the "*Prescriptive Study*" stage of the overall project research methodology, as described in Section 1.6.

The purpose of this experiment, as described in Section 6.1, was to deal with research objectives 2, 3 and 4 of this research project. To achieve this, the experiment needed to allow the following:

- To capture and study domain context from aerospace engineering domain.
- To proposed a context capturing approach to capture domain context in a cost-effective manner.
- Develop a context aware system to support aerospace knowledge work, and evaluate its impact in an operational setting.

A context capturing FBCC was proposed to allow Feedback Based Context Capturing. This context capturing approach was designed to allow knowledge workers to be closely involved in the context capturing work by providing feedback to the context model while the information systems are being used. The overview of FBCC is presented in Section 6.3. It was proposed to overcome the genuine problems highlighted by the early background reviews and evaluations.

The experiment needed to be positioned in an organisation setup within a targeted engineering domain, clearly defined use case and role of users. These elements are addressed in Section 6.4, where the Wing ISS engineering domain was chosen for in-depth domain context investigation. The engineering activity of repair case search was selected as the use case for the experiment. The repair case curator was to provide feedback to the context model during the experiment deployment period. Other In-Service engineers were to use the proposed context aware system to perform repair cases search.

The engineering use case for the experimental setup is further presented in detail in Section 6.5. Two types of context were captured in this experiment: semantic context and effective search terms. The system Daedalus was developed as a context aware repair case search tool for In-Service Engineers. Daedalus provided the capability to utilise the captured context to perform search terms expansion and search terms suggestion.

The empirical study and evaluation approaches for the experiment results are presented in Section 6.6. Reflecting the purpose of the experiment, the focus of the empirical study and evaluation activities were: In-depth Examination of Wing In-Service Support semantic context, evaluating FBCC approach, and evaluating Daedalus the context aware system.

7 Daedalus: A Context Aware System for Repair Case Search

In Chapter 6, the overall design of an experiment to capture and utilise context of aerospace knowledge work has been presented. As part of the key deliverables of this experiment to fulfil the research objectives, the context aware system Daedalus had to be developed.

Daedalus provides text-based search functionality for In-Service engineers to search for repair cases. To support this core functionality, context aware capabilities were implemented as part of the experiment. These include the functionality for users to capture domain context via simple spreadsheet interfaces, and two functionalities to utilise the captured context in the forms of search terms expansion and search terms suggestion.

In this Chapter, the detailed implementation of Daedalus is presented. In Section 7.1, the scope of Daedalus is discussed. The overall development approach is then presented in Section 7.2, introducing the phase based and modular design approach. The requirement specification is outlined in Section 7.3, specifying key functional and non-functional requirements for Daedalus' implementation. The system architecture of Daedalus is covered in Section 7.4 to introduce core modules and their interactions. A discussion about the choice of development tools is presented in Section 7.5 to provide the rationales behind key technical choice. Use case for core functionalities of Daedalus including sequence diagrams are presented in Section 7.6. Finally, the detailed implementation of Daedalus is presented in Section 7.7.

7.1 Scope of Daedalus

Daedalus was conceived and developed as a context aware system for repair case search in the Wing In-Service Support (ISS) department of Airbus. It served as a platform to enable the application of FBCC to capture domain context, and to test and demonstrate how the captured context can be utilised to support aerospace knowledge work. The context aware capabilities that were implemented as part of Daedalus include: the capability to allow user to capture context, and the two functionalities to utilise context as described in subsection 6.5.2.

From a research perspective, Daedalus was developed as a key deliverable of an experiment to capture and utilise context of aerospace knowledge work. It was via the usage of Daedalus that experimental outputs were generated to enable the following empirical study and evaluation activities:

- In-depth Examination of In-Service domain semantic context
- Evaluating the cost-effectiveness of FBCC approach
- Evaluating the adoption level and impact of Daedalus on Wing ISS engineering activities.

With relation to the technical aspects of context aware systems reviewed in Chapter 2, the development of Daedalus focused on realisation of functionalities which 1) allow non-IT expert user to perform context capturing using simplistic semantic representation; and 2) allow the captured context to be utilised in the form of search term expansion and search term suggestion. To this extend, technical focus of Daedalus was not to investigate new context modelling approaches nor automatic context reasoning mechanism, instead it served as a experiment platform to examine if domain context can be captured in an cost-effective manner with the FBCC approach.

From a software engineering aspect, the design, development and deployment of Daedalus were not intended to be a full-scale software development project which could include significant effort to provide operational quality assurance, maintenance and support. Instead, the focus during the development of Daedalus was on the realisation of experimental context aware capabilities, and ensuring the experiment output can be generated in a manner that is suitable for further empirical study and evaluation activities.

However, due to the industrial setting of this project – Daedalus quickly became the main repair cases search tool by engineers. Since its deployment in April 2011, measures were taken with the author's support to ensure the continuation of technical support, as well as the roll out of Daedalus in other Airbus location beyond the scope of this project. These activities are briefly discussed in Section 9.6.

7.2 Overall Development Approach

The overall development approach for Daedalus is introduced in this section. This overall approach had two aspects, the first aspect was phased based agile development as described in subsection 7.2.1, and the second aspect was modular design as described in subsection 7.2.2.

7.2.1 Phase-based Agile Development

From a software engineering point of view, the development process of Daedalus followed the agile software development approach (Beck, et al., 2001). The aim was to allow various core functionalities of Daedalus to be developed to fulfil intended purpose without prolong testing and re-development cycles. During the development period, the author, collocated with the Wing ISS in Filton, worked closely with both the repair case curator and other In-Service Support engineers in a multi-phased development process.

This multi-phased development process is illustrated in Figure 7-1. Within this development process, each literation was focused on specific core functionalities with relatively short development, testing and user-acceptance testing lead time. As shown in Figure 7-1, these five core functionalities are:

- **Basic Repair Case Search and Usage Profiling:** These two functionalities provides the basic capability for the user to search repair cases using text based search term, as well as the capability to capture key usage information.
- **Semantic Context Capturing**: This functionality allows the user to capture semantic context of the Wing ISS domain, as described in subsection 6.5.1

- **Effective Search Terms Capturing**: This functionality allows the user to capture effective search terms, as described in subsection 6.5.1
- **Search Terms Expansion:** This functionality provides the context aware capability for Daedalus to provide search terms expansion to argument the basic repair case search functionality.
- **Search Terms Suggestion:** This functionality provides the context aware capability for Daedalus to provide effective search terms as search terms suggestion.

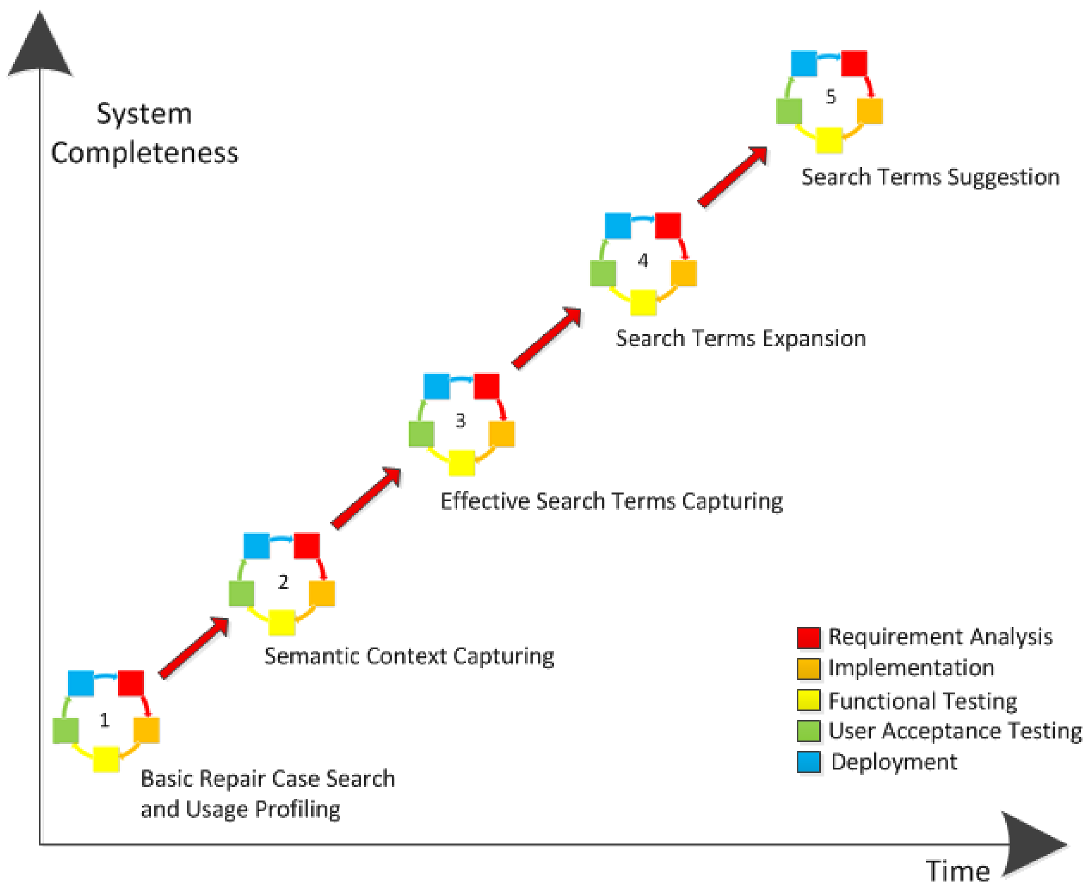


Figure 7-1: Implementation Phases of Daedalus

This multi-phased agile approach, and the modular design described in subsection 7.2.2, allowed the author to tailor the component development activity to fit with the different phases of FBCC discussed in subsection 6.4.3. As shown in the above figure, starting with basic search and usage profiling functionalities in phase 1, each additional phase introduce incremental functionalities which eventually provide the context aware capabilities that were required for the experimental application of FBCC.

The sequence of execution of the above implementation phases were designed to accommodate the application of FBCC. In particular, implementing the repair cases case search functionality in phase 1 allowed in-service engineers to start using Daedalus to search for repair cases early on in the overall development. This allowed *Usage Profiling* phase of

FBCC, as discussed in subsection 6.4.3 to be started in the earliest opportunity, once the implementation in phase 1 of Daedalus was finished.

7.2.2 Modular Design

A degree of functional independence was introduced in the overall architectural design of Daedalus. The four core modules that are implemented are: *Search Module*, *Context Capturing Module*, *Usage Profiling Module* and *Context Model*. Each individual component can operate individually to provide specific functions to support the core functionalities shown in Figure 7-1.

The relationships between the core functionalities, the implemented module and the related requirements are presented here in Table 7-1. The detailed requirement specification is presented in Section 7.3, while the detailed information of each key module and the overall architectural design is presented in Section 7.4.

Functionality	Related Module (Sub-Module)	Related Requirement
Basic Repair Case Search	Search Module Usage Profiling Module	3.1 4.1 4.2
Semantic Context Capturing	Context Capturing Module Context Model	1.1 2.1
Effective Search Terms Capturing	Context Capturing Module Context Model	1.2 2.2
Search Terms Expansion	Search Module Context Model	3.3
Search Terms Suggestion	Search Module Context Model Usage Profiling Module	3.2 4.1

Table 7-1: Relationships between core functionalities, Daedalus modules and Requirements

7.3 Requirements Specification

In order to fulfil the core functionalities of Daedalus, as stated in Section 7.2, the resulted system need to satisfy related functional requirements. Additionally, non-functional requirements that are essential to the set up and deployment of the resulted systems also need to be satisfied. The identified functional and non-functional requirements are listed in the following:

Functional Requirements

1. **Context Capturing:** The system shall allow capturing of the following types of contextual information.
    - **1.1. Semantic Context:** The system shall allow the user to define the semantic concepts and relationships between related concepts in a given domain.
        - **1.1.1. Concept Capturing:** The system shall allow the user to identify any given domain concept.
        - **1.1.2. Relationships Capturing:** For any concept that is captured, the system shall allow the user to specify the following semantic relationships it has with other concepts.

1.1.2.1. **Synonyms and Acronyms:** The system shall allow user to specify concepts that are synonymous or acronymous to a given concept

1.1.2.2. **Hyponyms:** The system shall allow the user to specify concepts that are of hyponymous semantic relationships a given concept

1.2. **Effective Search Terms**: The system shall allow the user to specify search terms that provide effective search results. The term "effective search results" here refer to search results that provide a satisfying number of relevant results to the search query with given search terms

2. **Context Modelling:** After contextual information has been input by the user, contextual elements representing the captured contextual information shall be created and saved in the context model. The context model shall allow representation of the following types of contextual information:

2.1. **Semantic Context:** As specified in requirement 1.1, the context model shall allow representation of domain concepts as well as key semantic relationships in the form of synonyms, acronyms and hyponyms.

2.2. **Effective Search Terms:** As specified in requirement 1.2, the context model shall allow representation of effective search terms.

3. **Repair Cases Search:** The system shall provide facility for the user to search for repair cases by providing text search terms. The user shall be able to open the repair cases from the search result. The repair cases search functionality shall incorporate context aware functionalities that are required for the experiment, as specified in requirements 3.3 and 3.4.

3.1. **Basic Search:** The system shall provide repair case search functionality as specified by the following:

3.1.1. **Search Term Entry:** The system shall allow the user to input his/her search term by typing in a search box text entry field. The provided search term shall then be used to initiate the search process.

3.1.2. **Repair Cases Information:** The system shall allow user to perform search on the repair cases information that are available from the repair cases spreadsheets that are introduced in Chapter 4.

3.1.3. **Text-Based Search:** For any given search term (***ST)***, the system shall provide relevant repair cases as search results.

3.1.4. **Search Operator Support:** The system shall parse the provided search terms for the following search operator key words and symbol, and provide search operator support according to the following

3.1.4.1. **"And" Operator:** For search terms in the form of "***ST1 and ST2"***, where **ST1** and **ST2** are text-based search terms while "***and***" is a search operator, the system shall provide repair cases that are relevant to both search terms.

3.1.4.2. **"Or" Operator:** For search terms in the form of "***ST1 or ST2***", **the** system shall provide repair cases that are relevant to either one or both search terms.

3.1.4.3. Asterisk (*) Operator: For search terms that contain the character "*****", the system shall provide search results in the following manner:

- ***"*ST"*:** For search term ***ST*** which follows a "*****" character, the system shall provide all repair cases with words ending with text identical to ***ST***.
- ***"ST*"*:** For search term ***ST*** which is followed by a "*****" character, the system shall provide all repair cases beginning with words starting with text string identical to ***ST***.
- **"*ST*":** For search term ***ST*** which is contained in a pairs of "*****" characters, the system shall provide all repair cases that containing text string identical to ***ST***.

3.1.4.4. Double Quote ("") Operator: For search term ***ST*** which is contained by double quote **""**, the system shall provide all repair cases that contain words or phases that are identical to ***ST***.

3.1.5. Repair case opening: The user shall be able to open a repair case from the search results, provided that a PDF repair case document corresponding to the repair case is available.

3.2. Search Terms Suggestion: The system shall provide search terms suggestions to the user during his/her search term entry process. The suggestions displayed shall depend on what the user type.

3.3. Search Terms Expansion: The system shall perform search terms expansion for search term ***ST*** if: ***ST*** contain concept ***C*** of which synonyms, acronyms or hyponyms are captured in the context model.

3.3.1. Synonym Expansion: For any given concept ***C***, if synonyms ***Sym1***, ***Sym2*** ... ***SymN*** are captured in the context model, the system shall substitute ***C*** in the original search term with ***Sym1 and Sym2 and*** … ***SymN***.

3.3.2. Acronym Expansion: For any given concept ***C***, if acronyms ***Acr1***, ***Acr2*** … *AcrN* are captured in the context model, the system shall substitute ***C*** in the original search term with ***Acr1 and Acr2 and*** … ***AcrN***.

3.3.3. Hyponym Expansion[10]: The hyponym expansion was implemented after the specific need for hyponym was identified after the Usage Profiling Phase. This requirement was specifically implemented to capture hyponyms for *specific parts*, such as ribs, spar and beam. This type of expansion is applied if the following conditions are met:

- The concept ***C*** is captured as a hyponym of concept ***B.***
- ***C*** is in the syntactic form of "***B n*"** where **n** is a number.
- Synonyms or acronyms of concept ***B*** are captured in the context model
- If the above condition are met, the system shall perform the following expansion:

  Step 1: the system shall substitute **C** with the syntactic forms of "**Bn**"

  Step 2: System shall perform semantic expansion for concept "***B***" in "**B n**" according to requirements 3.3.1 and 3.3.2

4. **Usage Profiling:** The system shall profile key usage information regarding to repair case searching and document opening.
   4.1. **Search Activities Profiling:** The system shall profile the following information related to search activity:
      - Search term
      - Search time and date
      - Repair case repository being searched
      - User ID
      - Selection of search suggestion
   4.2. **Document Opening Activity Profiling:** The system shall profile the following related to document opening activity:
      - The identification number of the opened document
      - Document opening time and date
      - Repair case repository containing the opened document

Non-Functional Requirement[11]

5. **Simplification of Context Capturing:** The context capturing functionality shall allow engineering users who are not information specialists to perform capturing of targeted contextual information.

6. **Understandability of Context Model:** The context modelling scheme shall ensure a level of simplicity which engineering users who are not information specialists can perform visual examination, and shall be stored in a neutral format which daily information editing tool can open and edited.

7. **Integration with Existing ICT Toolset:** The introduction of the system shall not required additional installation in corporate ICT environment.

8. **Integration with Existing Process:** Introduction of the system shall be easily integrated into In-Service engineers existing way of working to search for relevant repair cases.

7.4 Daedalus System Architectural Overall View

In this section, an overview is presented on the architecture of Daedalus. This overview highlights the overall layout and interactions between each key component. The four top level requirements of Daedalus as specified by the functional requirements in Section 7.3 are each implemented in the form of a module in this architecture. These components and interactions are illustrated in Figure 7-2.

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[10] The Hyponym expansion of Daedalus is to handle specific hyponym requirements naming conversion such as “Panel 1”, “Panel 2” and “Panel 3” where the synonym “PNL” for “Panel” can be applied all three hyponyms in the forms of “PNL 1”, “PNL 2” and “PNL 3” respectively

[11] The numbering of the non-function requirements follows that of the functional requirements.

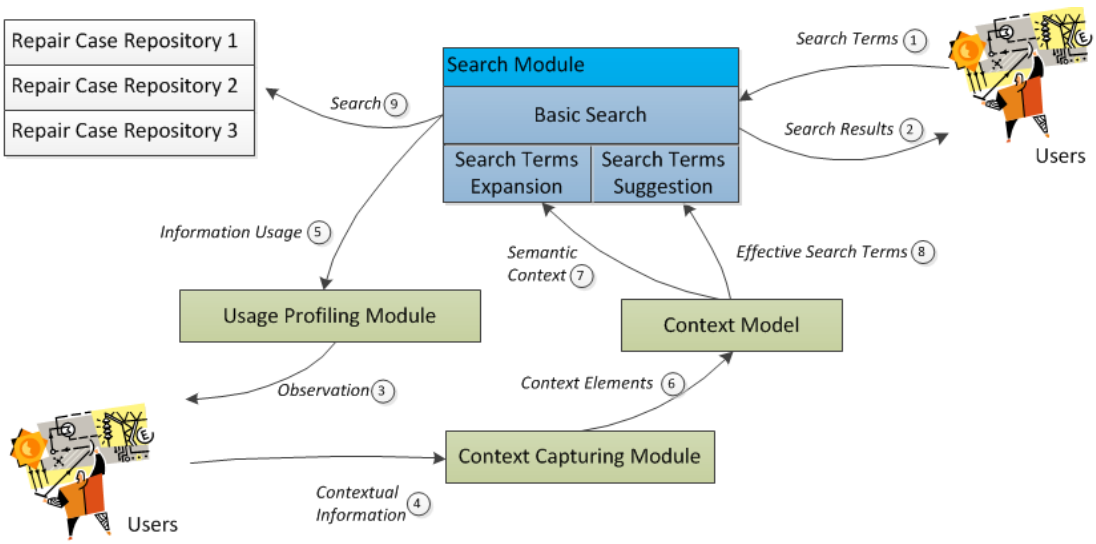


Figure 7-2: Daedalus Architecture Overall

As shown in Figure 7-2, the architecture of Daedalus contains the following modules:

- **Context Capturing Module:** This module was implemented to allow users to capture contextual information in the form of semantic context and effective search terms. This module provides functionalities that are specified in requirement 1 "Context Capturing".
- **Context Model:** This is a context model which stores the captured contextual information. This module provides functionalities that are specified in requirement 2 "Context Modelling"
- **Search Module:** This module was implemented to allow users to perform text-based search on key repair cases repositories. It provides the functionalities that are specified in requirement 3 "Repair Cases Search".

  This module provides repair cases search and the context aware functionalities that are core to Daedalus and is further divided into following sub-modules:
    - **Basic Search:** This sub-module provided repair cases search functionalities such as search terms parsing and performing search on the repair case repositories.
    - **Search Terms Expansion:** This sub-module provides the functionality to expand search terms based on the captured semantic context.
    - **Search Terms Suggestion:** This sub-module provide the functionality provide search terms suggestion based on the captured effective search terms.

- **Usage Profiling Module:** This module was implemented to perform profiling of repair case usage by the engineers. Its purpose was to capture key usage details such as search terms, document opening actions, and selection of search suggestion, search time and date, etc. This module provides functionalities that are specified in requirement 4 "Usage Profiling".

The key interactions illustrated in Figure 7-2 can be grouped into following three categories: 1) Interactions between the user and Daedalus; 2) Inter-component interactions within Daedalus and 3) Search Module Operations. These are described in Tables 7-1, 7-2 and 7-3:

User and Daedalus Interactions	
Identifier	**Description**
Interaction 1	The user uses search terms to initiate a search event.
Interaction 2	Search Module provides the user with search results.
Interaction 3	The user extracts key usage information as contextual information by performing manual observation.
Interaction 4	The user provides contextual information as feedback into the context capturing module.

Table 7-2: Interaction between Users and Daedalus

Inter-Components Interactions	
Identifier	**Description**
Interaction 5	Usage data are recorded by the Usage Profiling Module.
Interaction 6	Contextual Information is stored as context elements in the Context Model.
Interaction 7	Semantic context is used to facilitate search terms expansion.
Interaction 8	Effective search terms are used to facilitate search terms suggestion.

Table 7-3: Inter-Components Interactions

Search Module Operation	
Identifier	**Description**
Interaction 9	The search module performs search operations on the repair case repositories to retrieve matching repair cases.

Table 7-4: Search Module Operation

Although only one Search Module Operation is presented in Table 7-3, the search module is the most complex module in Daedalus, and it is worthwhile to further discuss this module on a component level. This is presented using UML sequence diagrams in Section 7.5.

7.5 Choice of Development Tools

During the design and implement of Daedalus, an important topic to consider was the choice of development tools in that such tools needed to be suitable for the specific research and industrial settings of this project. Development tools chosen for the implementation of different components of Daedalus are presented in the following Table 7-5, alongside with alterative options that were considered:

Component	Selected Tool	Alternative Options

Search Module	Microsoft Excel and VBA	Vivisimo Velocity
Usage Profiling Module	Microsoft Access	Vivisimo Velocity
Context Model	XML-based taxonomy	Ontology, RDF
Context Capturing Module	Microsoft Excel and VBA	Protégé

Table 7-5: Selected development tools

The rationales behind these choices are discussed in this section. Due to the technical interdependency between components, the selection of development tools for *Search Module* and *Usage Profiling Module* is discussed in the same subsection in subsection 7.5.1. Likewise, the corresponding discussion for Context Capturing Module and Context Model is discussed in subsection 7.5.2.

7.5.1 Search Module and Usage Profiling Module

The *search module* was the most complex component of Daedalus, offering the text-based search capability on the repair case repository as well as the proposed context aware capabilities. On one hand this module needed to perform typical search engine functionalities such as search query parsing and information indexing, on the other hand specific features of such functionalities needed to be configurable to utilise domain context. As for the *Usage Profiling Module*, from a functional point of view, the functionalities provided by this module can be regarded as part of the basic functions that are performed by typical search engine applications. In the frame of this research, this module is separated from the search module, due to its significance in gathering data for both domain context investigation and context feedback.

During the development of Daedalus, a key technical selection decision was to decide whether the implementation of the these two modules would be based on an enterprise search engine which provided these functionalities, or alternatively invest effort to construct basic functionalities in text-based search and Usage Profiling based on the specific need of this experiment.

In order to fully explore the advantage and disadvantage of basing the implementation on off the shelf enterprise search engine software, a demonstrator was created using Vivisimo Velocity (Xie, Culley, & Weber, 2011a). At the time of this study, Vivisimo Velocity was in the process of being implemented as the standard search engine within Airbus. Its core functionalities supported both text-based search and search activity profiling. Additionally, this software allowed user customer made context model to be integrated with the search engine to provide search terms expansion and search terms suggestion. For this reason, it was considered as a promising choice of implementation for this experiment to base on off-the-shelf solutions. This demonstrator provided rich functionalities in text-based search, also provided a good illustration on how engineering information retrieval can be done with state of the art search engine application. For example, the following Figure 7-3 illustrates how search term semantic expansion can be achieved with Vivisimo.

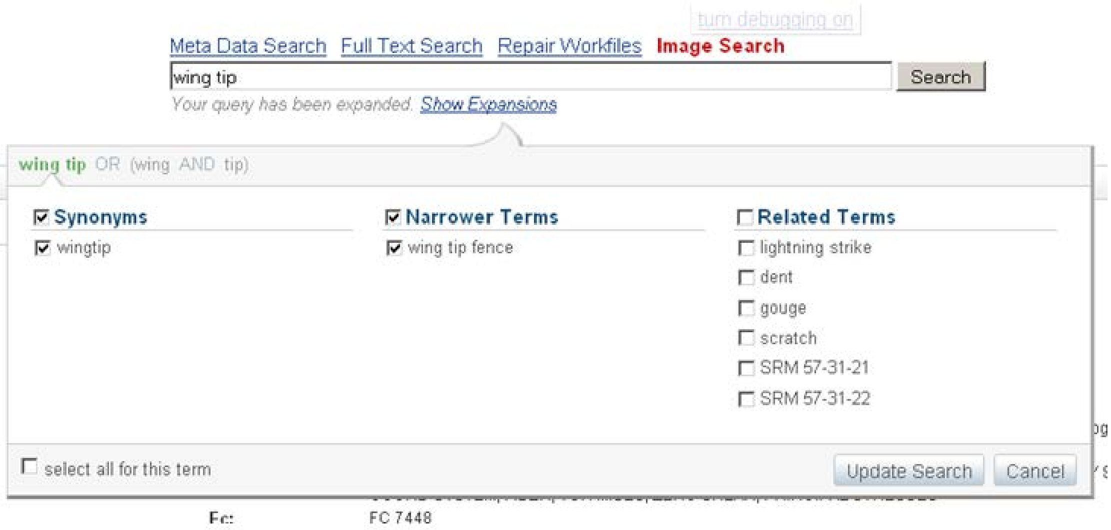


Figure 7-3: Vivisimo demonstrator for repair case search

However, it was concluded that conducting the experimental application of FBCC on such an off-the-shelf commercial application would create too many constraints for this research project. These include:

- **Long development cycle**: Development of applications using these types of industrial solutions would require strict application of an organisational ICT development process. These types of processes are tailored for full-scale software development projects rather than the experimental development being conducted. The development cycle of such full-scale project was too long for the allowed time for this research project.
- **Flexibility and Accessibility of usage capturing:** The usage capturing capability of the Usage Profiling Module needed to be tailored for the requirement of this project's on-going investigation. Such flexibility was not offered by the information capturing capability of Vivisimo Velocity. Additionally, the accessibility of the usage information captured by Vivisimo Velocity was tailored for expert-level administrator users. The accessibility of such information would have been to limited for the knowledge worker to perform the special type of contextual information feedback proposed by FBCC
- **Extensive functionalities:** In additional to standard text-based search functionality, Vivisimo Velocity also provides extensive advanced capabilities such as information clustering and social bookmarking. Although such functionality could be very beneficial features from a user point of views, they were not the focus of the research topics to be investigated, and would have diverted the effort required to implemented the experiment.

For these reasons, it was decided to base the development of Daedalus on Microsoft Office solutions. The Search Module was to be developed using Visual Based for Application (VBAs) on MS Excel, while the Usage Profiling Module was to be developed in using VBA on MS Excel and MS Access.

This allowed the implementation of Daedalus to satisfy non-functional requirements 7 "Integration with Existing ICT Toolset" and 8 "Integration with Existing Process". MS Excel was already used by the Wing ISS department to manage their repair case documents, and the flexibility to perform VBA programming on this tool allowed ideal flexibility to the agile development, as well as the required level of integration with existing engineering processes and tools. Similarly, the flexibility of constructing tailored-made and yet simple dataset using MS Access were ideal for the usage profiling requirement of this research project.

7.5.2 Context Capturing Module and Context Model

The consideration of development tools for the *Context Capturing Module* and the *Context Model* were mainly based on how the eventual choices might satisfy the non-functional requirements 5 "*Simplification of Context Capturing*" and 6 "*Understandability of Context Model*". The application of FBCC replied on knowledge workers to perform feedback to contextual information that are captured. However, as identified in subsection 5.1.3, there is a lack of a context capturing tool tailored for non-specialist users. For this reason, although it was not the aim for this research to develop contextual capturing tool that overcome this technological barrier, it was essential that the *Context Capturing Module* and the *Context Model* would allow *engineer users* to capture and review contextual information of interest in this experiment, namely semantic context and effective search terms, in a simple and straight forward manner.

For the *Context Capturing Module*, it was decided that VBA on MS Excel will be used for the development. The aim was to provide a simple interface on traditional office application specifically for capturing the two type of contextual information of interest. This choice allowed the *Context Capturing Module* to be available on information tool which engineers used on a daily basis, and ensured the level of user familiarisation of the resulted interface and integration with the daily work. Additionally, developing the *Context Capturing Module*, the *Search Module* and the *Usage Profiling Module* using VBA of MS Office solutions helped to reduce the complexity of the development effort and simplify the functional interactions between different components

For the *Context Model*, XML-based semantic modelling standards OWL and RDF were considered, however it was decided not to use these standard for the following reasons: 1) At the time of development, there was very few existing technical solution developed using VBA for OWL or RDF interoperability, and the additional effort needed for creating such capability would be substantial and was also out of the scope for this research. 2) These standards, although well accepted by computing professionals, would pose considerable learning barriers for non-IT expert users who would perform context capturing during the experiment. In particular, notations standard related to resource definition, relationships, class, entity and instance would cause difficulties for non-IT expert users to understand and review the captured context.

Based on the above discussion, it was decided that a simple XML format would be used to represent the contextual information captured during the experiment. Details of the chosen XML format for the *Context Model* are presented in subsections 7.7.3 and 7.7.4. This XML format was based on the XML-based "*ontolection*" that were used by the enterprise search engine Vivisimo Velocity to facilitate semantic expansion (IBM, 2013). For this reason, this choice made it technically straightforward for the resulted context model of this experiment to be reused. Additionally, the simplicity of this for allowed the possibility for engineer users to perform simple visual check on the captured contextual information.

7.6 Use cases for core functionalities of Daedalus

The core functionalities of Daedalus are outlined in subsection 7.2.1. The realisation of these core functionalities enabled the deployment of Daedalus in the Wing ISS Department both as a useful tool and also a research platform. Use cases for these for functionalities are presented from subsections 7.6.1 to 7.6.5. For each use case, UML sequence diagrams were used to illustrate the interactions between various modules, sub-modules and non-system objects such as users and repair case repositories.

7.6.1 Basic Repair Cases Search

The sequence diagram in Figure 7-3 illustrates how users can use Daedalus to search for repair case documents. Although this sequence diagram also includes how the search terms suggestion and search terms expansion functionalities are positioned in the overall search routine, the focus of the discussion in this subsection is on the use case for the basic repair cases search functionality. Detailed discussions about the use case for search terms suggestion is presented in subsections 7.6.4, while detailed discussion about the use case for search terms expansion is presented in subsection 7.6.5.

As shown in Figure 7-4, the user starts by typing the search term he/she wants to search for in the text search box. The *Search Module* monitors what has been typed in by user and provides search terms suggestions accordingly. At this point, the user has the choice to choose one of the search terms provided in a suggestion list as the search term applied in repair cases search. If a search term is chosen from the list, the *Search Module* will record the user's action of selecting search suggestion in the *Usage Profiling Module*. Alternatively, the user can proceed to finish typing the entire search term as desired before starting the repair case search.

Once repair cases search activity begins, the *Search Module* records key information about the search activities into the *Usage Profiling Module*. This include the search term, repair case repository being searched, user ID, search date and search time.

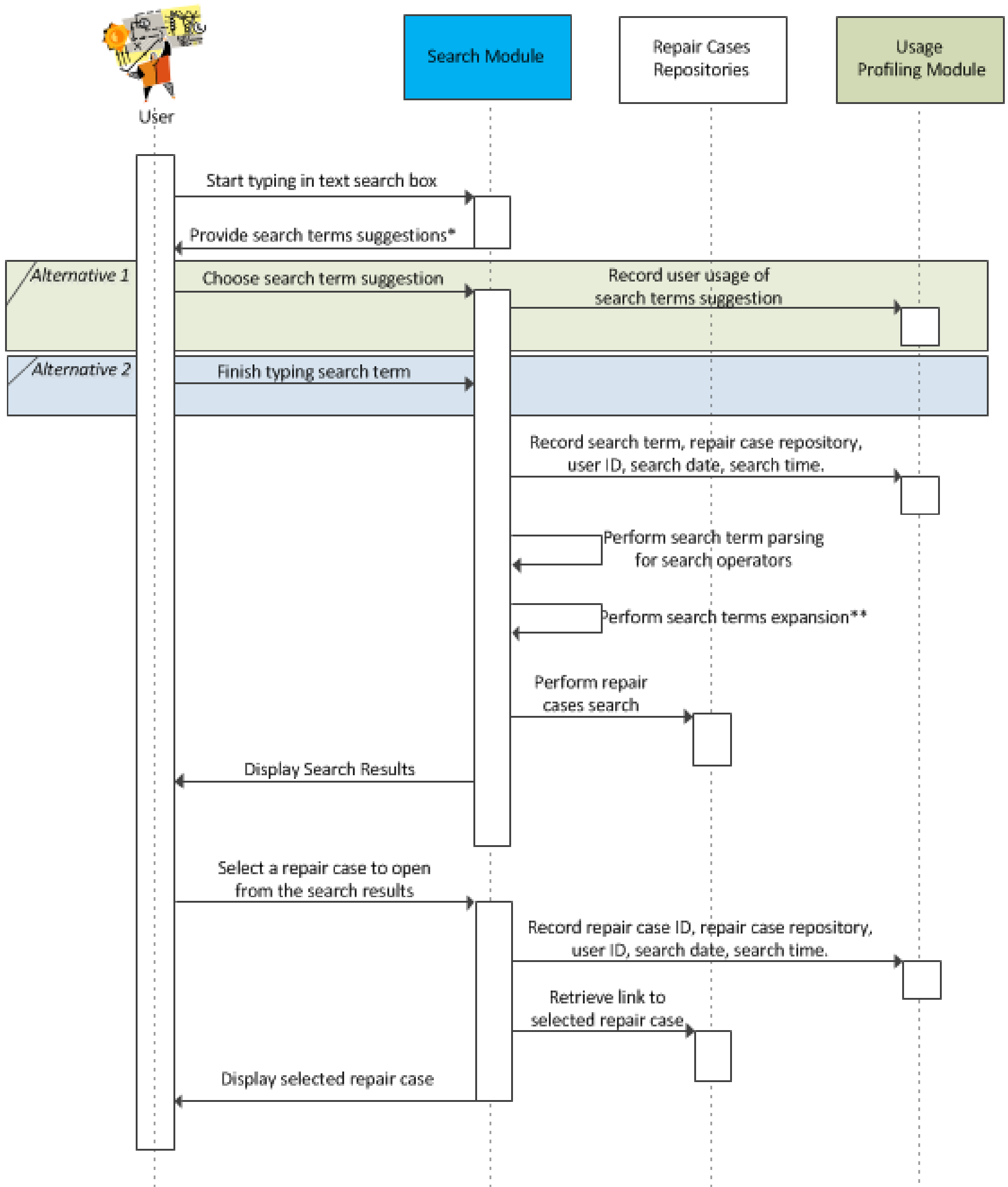


Figure 7-4: Sequence Diagram for Basic Repair Cases Search

The Search Module then performs search terms parsing according requirements 3.1.4 "Search Operator Support" specified in Section 7.3. Search terms expansion is then taken place. This will be further discussed in subsection 7.6.4.

After performing search terms expansion, the *Search Module* search the targeted repair case repository with the parsed and expanded search term, identifying the relevant repair cases, and display them on the user interface.

7.6.2 Semantic Context Capturing

The sequence diagram in Figure 7-5 illustrates how semantic contexts are to be captured in Daedalus. The user starts by selecting to load all the previously captured concepts, this action triggers the *Context Capturing Module* to retrieve from the *Context Model* all the

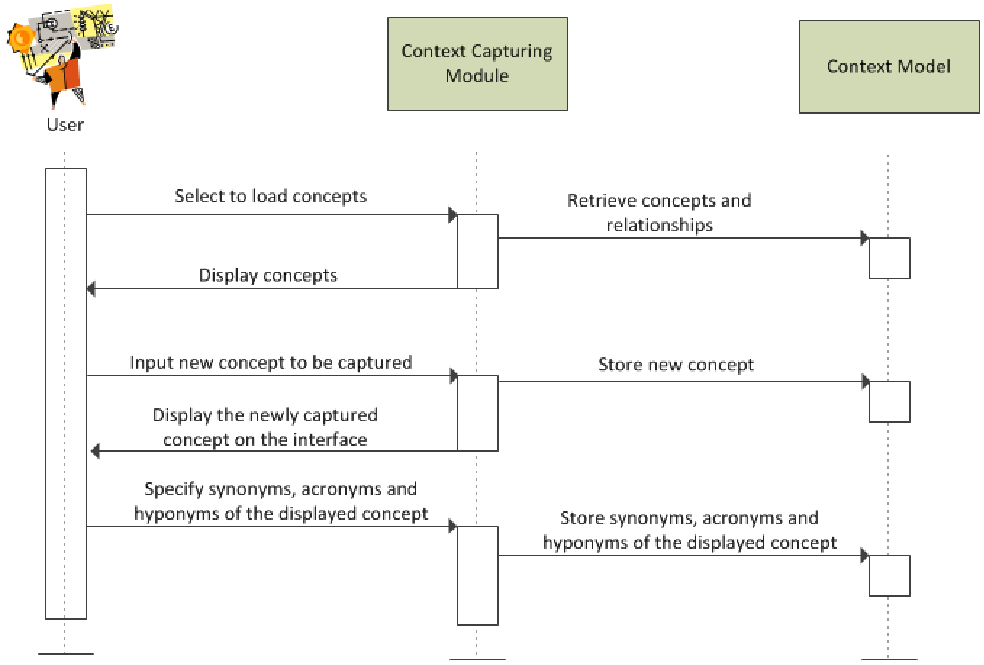


Figure 7-5: Sequence Diagram for Semantic Context Capturing

Concepts and semantic relationships associated with these concepts. After this action is finished, the *Context Capturing Module* displays all the captured concepts on the interface of *Context Capturing Module*.

In the next step, the user input a new concept that is to be captured, this triggers the *Context Capturing Module* to store the new concepts into the *Context Model*, and then display the newly captured context on the interface.

In the final step, the user specifies all the semantic relationships that need to be captured. Each instance of relationship is defined by specifying the term that is related to the concept, and the type of relationship.

7.6.3 Effective Search Terms Capturing

The sequence diagram in Figure 7-6 illustrates how effective search terms are to be captured in Daedalus. The user starts by selecting to load all the previously captured effective search terms. This action triggers the *Context Capturing Module* to retrieve from the *Context Model* all the effective search terms currently stored. After this action is finished, the *Context Capturing Module* displays all the existing effective search term on the interface of *Context Capturing Module*.

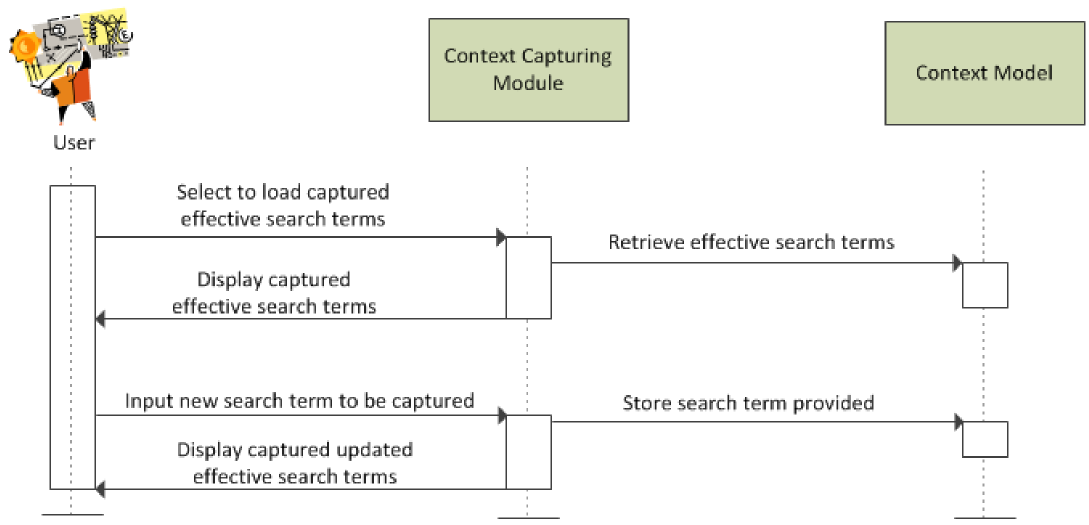


Figure 7-6: Sequence Diagram for Effective Search Terms Capturing

In the second step, the user inputs a new effective search term that is to be captured, this triggers the *Context Capturing Module* to store the new effective search term into the *Context Model*, and then display the newly captured effective search term on the interface.

7.6.4 Search Terms Suggestion

The sequence diagram in Figure 7-7 illustrates how search terms suggestions are generated using effective search terms captured and stored in the *Context Model*. In this functionality, two sub-modules of the *Search Module* - *Basic Search* and *Search Terms Suggestion* are involved.

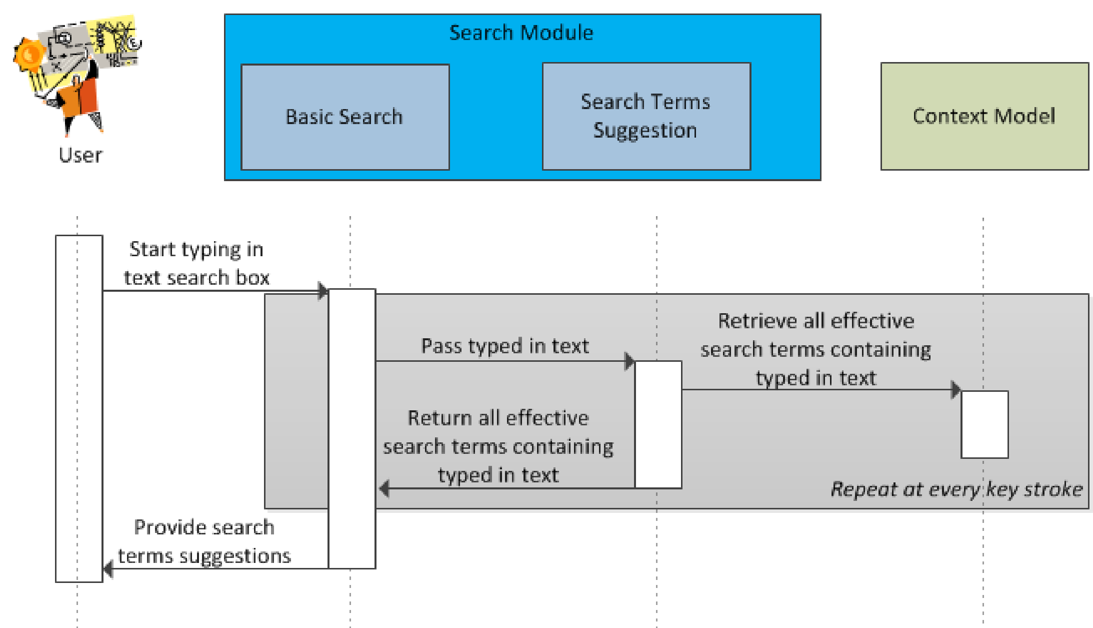


Figure 7-7: Sequence Diagram for Search Terms Suggestion

The user starts, as also shown in Figure 7-4, by typing search terms into the text search box. The *Basic Search* sub-module passes the typed-in text to the *Search Terms Suggestion* sub-module by monitoring the user's typing activity.

The Search Terms Suggestion sub-module then retrieves all the effective search terms from the *Context Model* that contains the typed in text, and returns them to the *Basic Search* sub-module which in turn displays these search terms in a suggestion list on the user interface.

The activities described above take place at every key stroke input by the user when he/she types in the text search box. This allows search suggestions to be changed interactively to what the user types in the text search box.

7.6.5 Search Terms Expansion

The sequence diagram in Figure 7-8 illustrates how search terms expansion is performed using semantic context captured in the *Context Model*. In this functionality, two sub-modules of the *Search Module - Basic Search* and *Search Terms Expansion* are involved.

After a repair case search is initiated, as shown in Figure 7-4, the *Basic Search* sub-module performs search term parsing according to requirement 3.1.4 "Search Operator Support", as specified in Section 7.3. As a result, the original search terms are translated into an array of tokens separated by search operators with each token in this array correspond a word in the search terms. The *Basic Search* sub-module then passes this tokens array to the *Search Terms Expansion* sub-module.

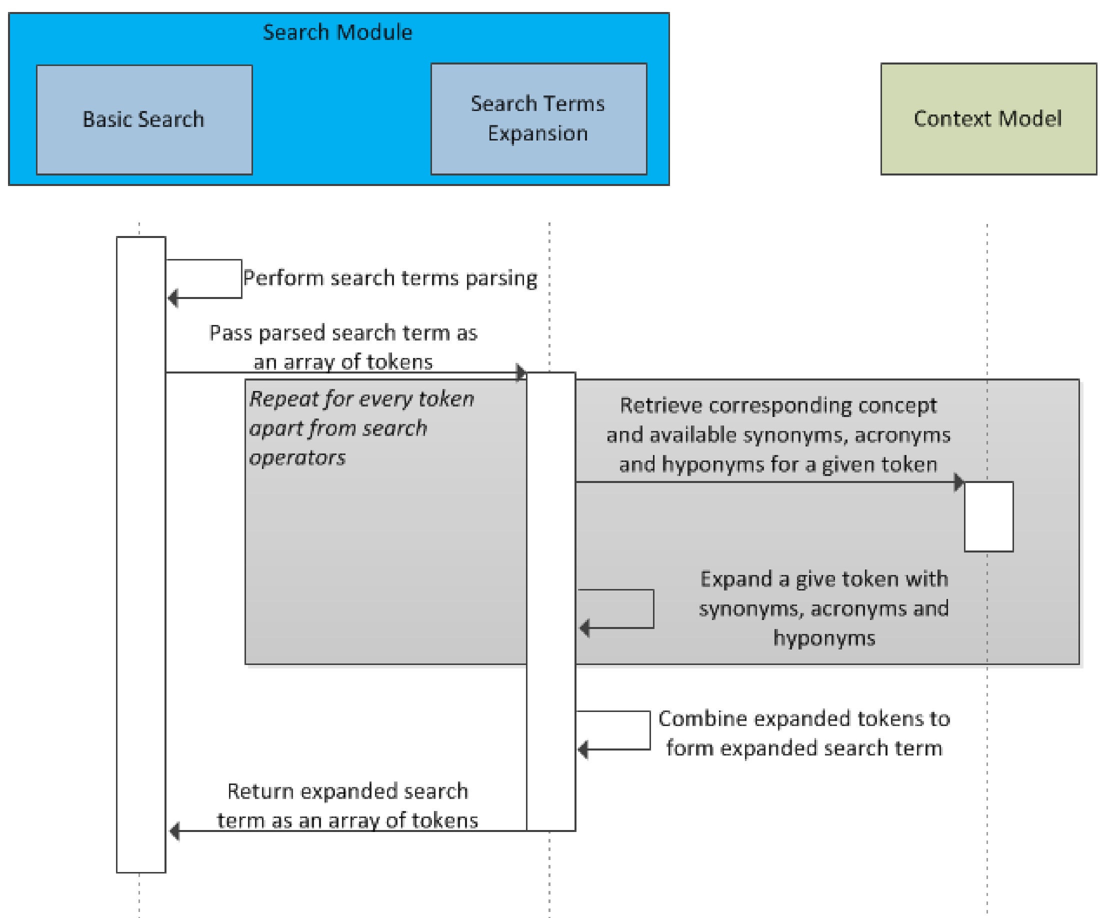


Figure 7-8: Sequence Diagram for Search Terms Expansion

After receiving the tokens array, the *Search Terms Expansion* sub-module performs the following for each token: Firstly, the concept correspond to a given token is retrieved from the *Context Module*, alongside any available synonyms, acronyms and hyponyms; secondly, search terms expansion is performed on each token as specified in requirement, as specified in requirement 3.3 in Section 7.3.

After each token is expanded, the *Search Terms Expansion* sub-module combines the expanded token to form the expanded search term, again in the form of a tokens array. This token array representing the expanded search term is then returned to the *Basic Search* sub-module to continue the search operation as illustrated in Figure 7-4. This final list of token is used by the search module to create the "Advance Criteria Filtering" setting as further illustrated in the example provided later in this Chapter in 7.7.5.

7.7 Detailed Implementation

The detailed implementation of Daedalus is presented in this section. As mentioned in Section 7.2, the development of Daedalus was divided into several agile development phases. Development in each of these phases was focused on one of the core functionalities introduced in 7.6. As discussed in 7.5, Microsoft Excel, Access and Visual Basic for Application were chosen as the main development tool, while a simple XML format were used for context modelling.

In this section, discussions of are presented to explain detailed implementation of each core functionalities from subsections 7.7.1 to 7.7.5. These discussions provide detailed explanation on how the chosen development tools were used to realise the core functionalities of Daedalus. Additionally, the implementation of the *Usage Profiling Module*, which provided the main data gathering mechanism of the experiment, is presented in 7.7.6.

7.7.1 Implementation for Repair Cases Search and Opening

As discussed in the sequence diagram in Figure 7-4 for this functionality, key steps for this functionality include the following:

- **Search term entry:** The user inputs search term with the option of using search suggestion or typing the search term in its entirety.
- **Search execution**: Interacting modules of Daedalus perform automatic function to parse and extend search term, and retrieve repair cases related to the input search term.
- **Displaying search results:** Search results are displayed to the user
- **Opening of Repair Case:** The user chooses to a repair case to open.

Compared to what is included the in sequence diagram, the implementation in discussed here was focused on the realisation of basic repair case search. As indicated in 7.2.1, this basic search functionality was implemented in phase 1 without search terms expansion and search terms suggestion. These two functionalities were the key focus of implementation phases 4 and 5 respectively, as suggested in Figure 7-1.

The following discussion contains two "search scenarios". The first search scenario provides details on how the four key steps above are implemented during a basic repair case search for a simple search term with one word. This is followed by a second search scenario in which search operators are used.

Search Scenario 1: Basic Repair Cases Search

The main interface in Daedalus for repair cases search is adapted and built on the repair cases spreadsheets that was already in used by the Wing ISS departments and was discussed in Section 4.3. At the time of this study, there were four spreadsheets, one for each of the following collection of repair cases: Single Aisle before and include 2004 (referred to as “SA pre2004”); Single Aisle after 2004 (referred to as “SA aft2004”); Wide body and long range before and include 2004 (referred to as “WB & LR pre2004”); Wide body and long range after 2004 (referred to as “WB & LR aft2004”). Additionally, during the development and deployment period of Daedalus, an additional spreadsheet was created by the repair cases for A380.

For each of these spreadsheets, modifications were performed to add a search interface as shown in Figure 7-9. As a result, Daedalus was not developed as a centralised system, but a collection of Excel Spreadsheets with advance search functionalities. As shown in Figure 7-9 for Daedalus for SA aft2004 repair cases, this search interface contains the following key elements:

- **Search Box**: a text box for search term entry
- **“Find ISQ” button**: a search button to launch search
- **“ISQ FILE” Button**: a button for opening daily ISQ repair case documents corresponding to the selected row in the repair cases information section.

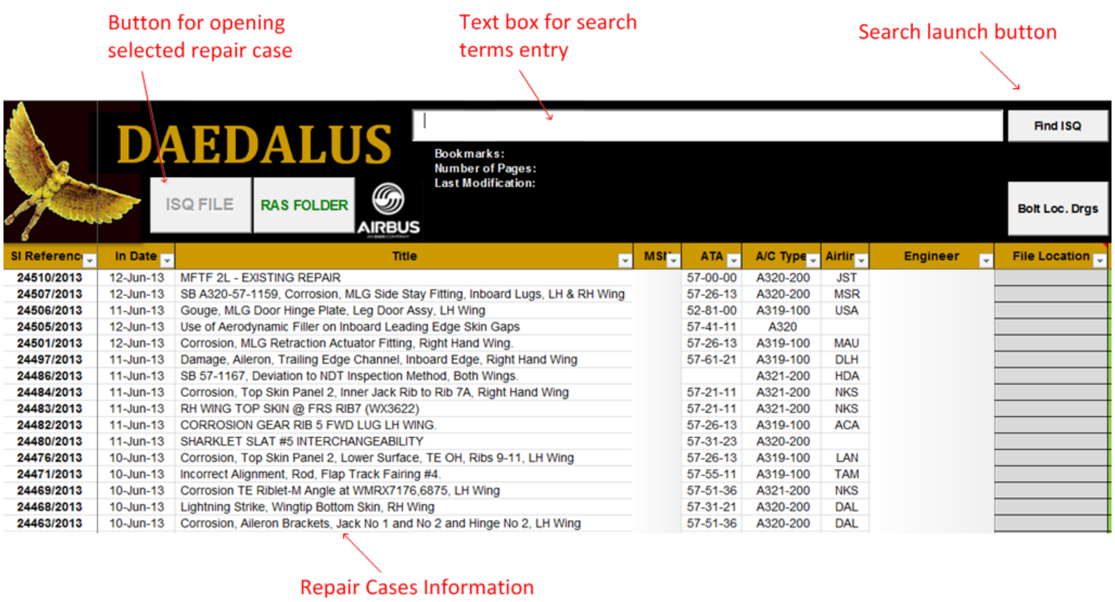


Figure 7-9: Interface for Repair Cases Search

The following discussion illustrates how the key steps for basic repair cases search and opening are implemented, using the search term “Aileron” as example:

1. *Search Term Entry*

   The user types in the search term, and click on the “Find ISQ” button to launch the search, as shown in Figure 7-10.

Figure 7-10: Text Entry in Search Box

2. *Search Execution*

   In Daedalus, the repair case search execution is implemented by utilising the "Advanced Criteria Filtering" function of MS Excel (Microsoft, 2012). This function allows the filtering of Excel spreadsheet using conditional criteria therefore. This is further discussed in the next search scenario.

SI Reference	Combine	-	-	-		-	-	-	-
21976/2012	21976/2012 , 12/12/2012 , Alternative Bearing Replacement Procedure, Aileron Hinge Ribs , 2477								
18560/2012	18560/2012 , 12/01/2012 , New Tool Query, On-Wing Bearing Removal/Installation, Aileron Hinge E								
14940/2010	14940/2010 , 20/12/2010 , Interchangeability query - Aileron Hinge Line Bearing - Both Wings , GE								
13135/2010	13135/2010 , 10/05/2010 , A-FRAME ON WING BEARING REPLACEMENT, AILERON HINGE LII								
12799/2010	12799/2010 , 31/03/2010 , Aileron Hinge Support frame - Alternative bearing replacement procedu								
11468/2009	11468/2009 , 30/10/2009 , Aileron Hinge Bearing - Alternative Part Usage , 1177 , 57-51-36 , A32								
09446/2009	09446/2009 , 11/02/2009 , Aileron Hinge Support arms bearing replacement tooling , GEN , 57-51								
06073/2007	06073/2007 , 19/11/2007 , RH Aileron hinge bearing check out of limit , 2254 , 57-51-36 , A320-2C								
05915/2007	05915/2007 , 22/10/2007 , Aileron hinge support frames, spherical bearing wear , 1907 , 57-51-36								

Figure 7-11: Combine Field

In order to exploit this function, a "Combine" field is created in each row of repair case information to combine all the available meta-data for each repair case into one data field, as seen Figure 7-11. This allows the "Advance Criteria Filtering" functional to filter repair cases using the criteria setting seen in Figure 7-12.

Combine
* aileron *

Figure 7-12: Advance Criteria Filtering

In this simple case of one-word search term, the criteria arranged in the format shown in Figure 7-11 instructs the Excel filter to filter for all repair cases containing the string " aileron " in the "Combine" field of the spreadsheet. This operation therefore allows Daedalus to display all the repair case containing the word "Aileron", as described in the following step.

3. *Displaying Search Results*

   The displaying of search results for the search term "Aileron" is shown in Figure 7-13. As described above, this is the result of using the "Advanced Criteria Filtering" to filter the "Combine" field.

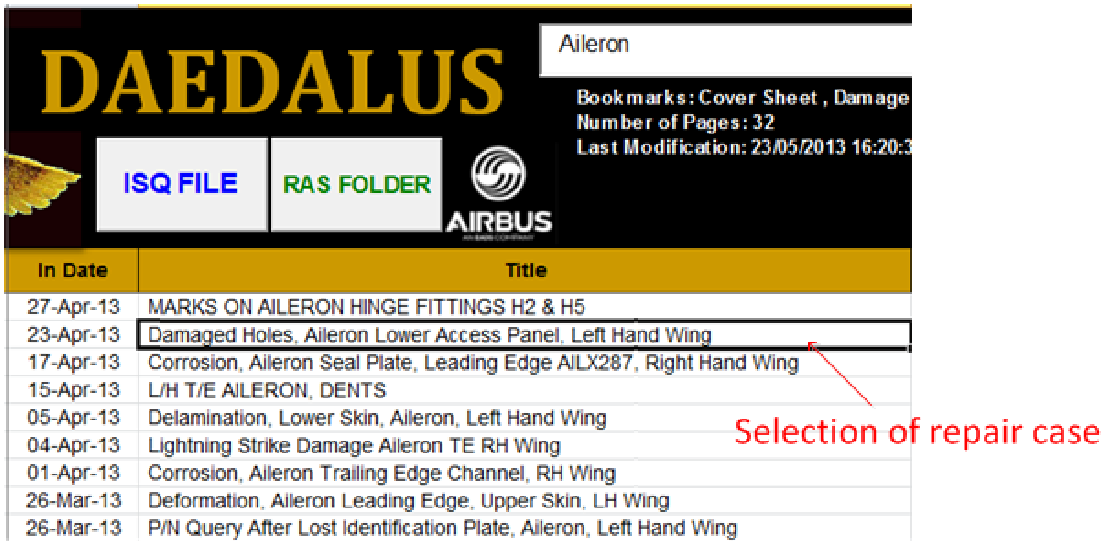


Figure 7-13: Selection of repair case

4. *Opening Selected Repair Case*

   When the user selects a repair case from the search result, Daedalus will automatically detected if a PDF repair case document, as described in Section 4.3, has been created for the selected repair cases. The "ISQ FILE" button will become available if such PDF document is available, and the user can open the selected repair case by clicking on this button.

Search Scenario 2: Repair Cases Search with Search Operators

The repair case search functionality allows users to use search operators, as described in requirement 3.1.4 "Search Operator Support", to augment their search activities. In Table 7-6, examples are given to illustrate how the "Advanced Criteria Filtering" faction was used to accommodate various search operators. Detailed description of each of these search operators, as well as example search results is given in the following text.

Search Operator	Example Search Terms	Advanced Criteria Setting with "Combine" field.
"And" operator	Aileron and Bearing	Combine: * aileron * / Combine: * bearing *
"Or" operator	Aileron or Bearing	Combine * aileron * * bearing *
Asterisk (*) operator	*interch*	Combine *interch*
Double Quotes (" ") Operator	"Upper surface corrosion"	Combine * upper surface corrosion *

Table 7-6: Advance Criteria Filtering settings for search operators

1. *"AND" Operator*

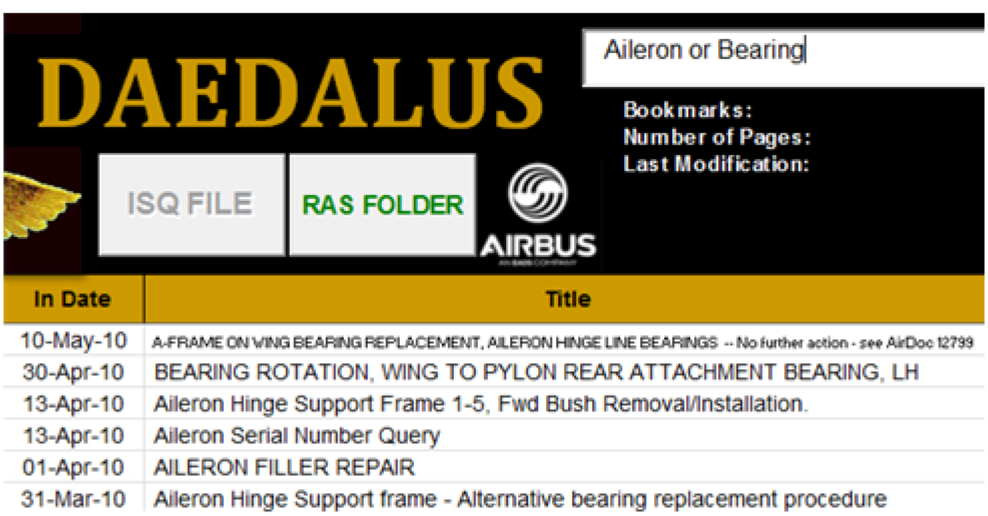
   The search result of the search term "Aileron and Bearing" is partly shown in Figure 7-14. This search term contain the search operator "And". The format for "Advanced Criteria Filtering" for this example is shown in the second row of Table 7-6. By arranging the criteria “* aileron *” and “* bearing *” side by side, this allows the filtering of data containing the both “aileron” and “bearing” in the “Combine” field, as specified in requirement 3.1.4.1 for “And” operator.

In Date	Title	MSN	ATA
20-Dec-10	Interchangeability query - Aileron Hinge Line Bearing - Both Wings	GEN	
10-May-10	A-FRAME ON WING BEARING REPLACEMENT, AILERON HINGE LINE BEARINGS -- No further action - see AirDoc 12799	-	
31-Mar-10	Aileron Hinge Support frame - Alternative bearing replacement procedure	GEN	
30-Oct-09	Aileron Hinge Bearing - Alternative Part Usage	1177	
11-Feb-09	Aileron Hinge Support arms bearing replacement tooling	GEN	
19-Nov-07	RH Aileron hinge bearing check out of limit	2254	
22-Oct-07	Aileron hinge support frames, spherical bearing wear	1907	
28-Mar-07	LH/RH Aileron Hinge bearing #3 corrosion	2685	
27-Mar-07	AILERON SPHERICAL BEARING ALTERNATIVE P/N.	1891	

Figure 7-14: Search result with “And” operator

2. *“Or” Operator*

The search result of the search term “Aileron or Bearing” is partly shown in Figure 7-15. This search term contains the search operator “Or”. The format for “Advanced Criteria Filtering” for this example is shown in the third row of Table 7-6. By arranging the criteria “* aileron *” and “* bearing *” in vertical order , this allow the filtering of data containing the words either “aileron” or “bearing” in the “Combine” field, as specified in requirement 3.1.4.2 “Or” operator .

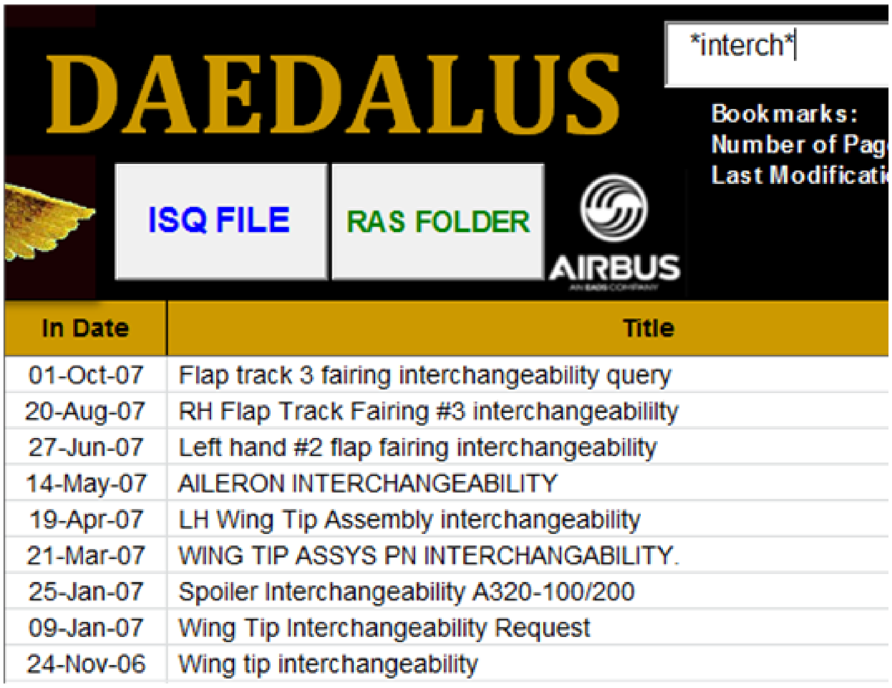


In Date	Title
10-May-10	A-FRAME ON WING BEARING REPLACEMENT, AILERON HINGE LINE BEARINGS -- No further action - see AirDoc 12799
30-Apr-10	BEARING ROTATION, WING TO PYLON REAR ATTACHMENT BEARING, LH
13-Apr-10	Aileron Hinge Support Frame 1-5, Fwd Bush Removal/Installation.
13-Apr-10	Aileron Serial Number Query
01-Apr-10	AILERON FILLER REPAIR
31-Mar-10	Aileron Hinge Support frame - Alternative bearing replacement procedure

Figure 7-15: Search result with “Or” operator

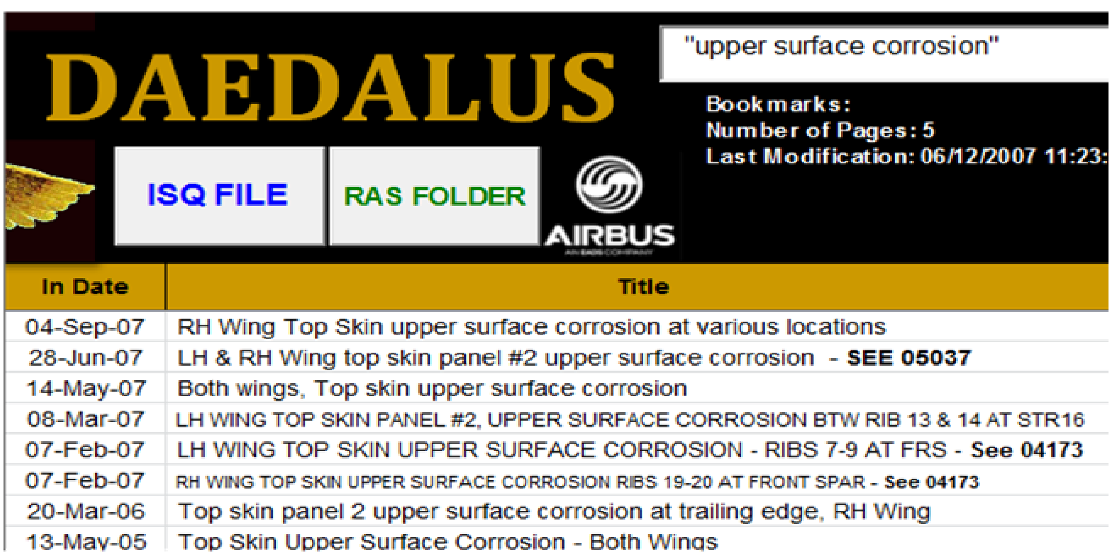
3. *Asterisk (“*”) Operator*

The search result of the search term “*interch*” is partly shown in Figure 7-16. This search term contains the search operator asterisk “*”. The format for “Advanced Criteria Filtering” for this example is shown in the fourth row of Table 7-6. By specifying the criteria to be "*interch*" , this allows the filtering of data containing text string identical to "interch" in the "Combine" field, as specified in requirement 3.1.4.3 for "Asterisk (*)" operator. The other two scenario "****ST***" and "***ST***" of this search operator follows same principle of "****ST****".



In Date	Title
01-Oct-07	Flap track 3 fairing interchangeability query
20-Aug-07	RH Flap Track Fairing #3 interchangeabililty
27-Jun-07	Left hand #2 flap fairing interchangeability
14-May-07	AILERON INTERCHANGEABILITY
19-Apr-07	LH Wing Tip Assembly interchangeability
21-Mar-07	WING TIP ASSYS PN INTERCHANGABILITY.
25-Jan-07	Spoiler Interchangeability A320-100/200
09-Jan-07	Wing Tip Interchangeability Request
24-Nov-06	Wing tip interchangeability

Figure 7-16: Search result with the asterisk "*" operator



In Date	Title
04-Sep-07	RH Wing Top Skin upper surface corrosion at various locations
28-Jun-07	LH & RH Wing top skin panel #2 upper surface corrosion - **SEE 05037**
14-May-07	Both wings, Top skin upper surface corrosion
08-Mar-07	LH WING TOP SKIN PANEL #2, UPPER SURFACE CORROSION BTW RIB 13 & 14 AT STR16
07-Feb-07	LH WING TOP SKIN UPPER SURFACE CORROSION - RIBS 7-9 AT FRS - **See 04173**
07-Feb-07	RH WING TOP SKIN UPPER SURFACE CORROSION RIBS 19-20 AT FRONT SPAR - **See 04173**
20-Mar-06	Top skin panel 2 upper surface corrosion at trailing edge, RH Wing
13-May-05	Top Skin Upper Surface Corrosion - Both Wings

Figure 7-17: Search result with double quote ("") operator

4. *Double Quotes (" ") Operator*

The search result of the search term "upper surface corrosion" is partly shown in Figure 7-17. This search term contains the search operator double quotes (""). The format for "Advanced Criteria Filtering" for this example is shown in the fifth row of Table 7-6. By specifying the criteria to be ""upper surface corrosion"" - adding double quotes before and after the searched content, this allow the filtering of data containing the exact phase “upper surface corrosion” in the “Combine” field, as specified in requirement 3.1.4.4 for Double Quote (“”) operator.

7.7.2 Implementation for Semantic Context Capturing

As discussed in subsection 7.5.2, MS Excel and VBA were used for the implementation of the *Context Capturing Module,* while the *Context Model* was constructed using a simple XML format. In subsections 7.7.2 and 7.7.3, the user interfaces for the *Context Capturing Module* are introduced, with examples of how contextual information can be captured via this interface, and how captured contextual information are stored using the chosen XML format in the *Context Model*.

For both the semantic context capturing and effective search terms capturing, simple interfaces were created based on Excel Spreadsheet. The interface for semantic context capturing is shown in Figure 7-18.

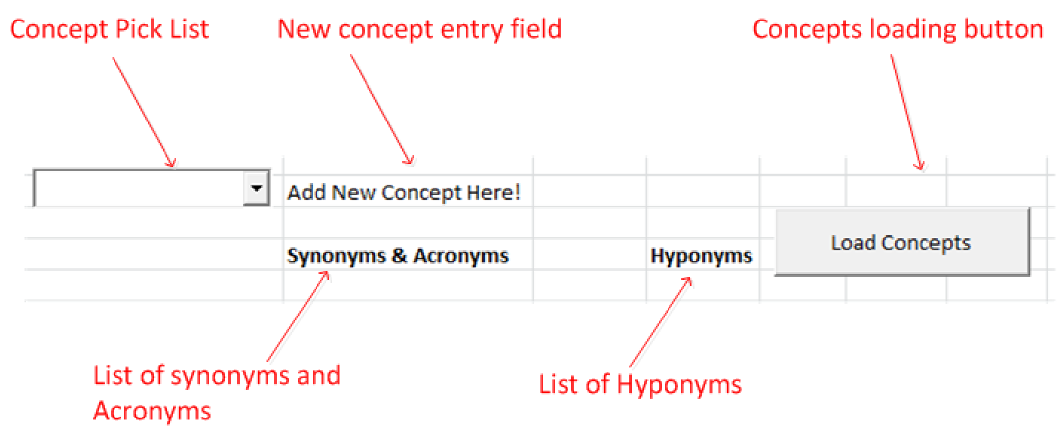


Figure 7-18: Interface for Semantic Context Capturing

As shown in the above figure, this interface contains the following elements for the user to perform various tasks to capture semantic context of domain concepts:

- **Concept Pick List**: This pick list contains a list of concepts which are already captured. The user can choose a concept from this pick list, as shown in Figure 7-19. When a concept is chosen, the synonyms, acronyms or hyponyms of this concept will be displayed, as shown in Figure 7-19.
- **New concept entry field**: The user can capture a new concept by typing the concept in this field.
- **Load Concepts button**: By clicking this button, the user can load the *Context Capturing Module* with all the concept and semantic relationships already captured in the *Context Model*.
- **Synonyms and Acronyms List**: Once a concept is chosen from the pick list, all the synonyms and acronyms related to this concept will be displayed in this list, as shown in Figure 7-19.
- **Hyponyms List**: Once a concept is chosen from the pick list, all the hyponyms related to this concept will be displayed in this list, as shown in Figure 7-20.

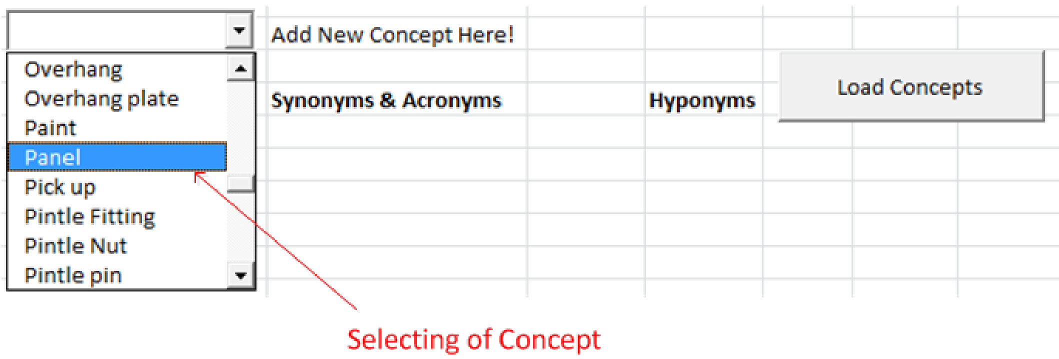


Figure 7-19: Selection of Concept

Figure 7-20: Display of Semantic Context

In Figure 7-20, an example is shown to illustrate how the concept “Panel” and related semantic relationships are displayed on the interface of the *Context Capturing Module*. The contextual information that is displayed on this interface is stored in the *Context Model* using XML tags. The section in the *Context Model* that stores the contextual information for the concept “Panel” is shown in Figure 7-21 below. As shown in this figure, this XML format utilises the following tags to handle different types of contextual information:

- **<concept> Tag**: This top level tag is used for the concept that is to be captured, by allowing the “name” element to be specified with the concept. For each concept that is captured, an entry of <concept> tag will be created in the *Context Model*.
- **<synarc> Tag**: This is second level tag is used to capture the synonyms and acronyms that are related with the associated concepts. For each synonym and acronym that is captured, an entry of <synarc> tag will be created under the <concept> tag entry corresponding to the related concept.
- **<hyponym> Tag:** This is second level tag is used to capture the hyponym that are related with the associated concepts. For each hyponym that is captured, an entry of <hyponym> tag will be created under the <concept> tag entry corresponding to the related concept.

```
<concept name="Panel">
    <synacr>PNL</synacr>
    <hyponym>Panel 1</hyponym>
    <hyponym>Panel 2</hyponym>
    <hyponym>Panel 3</hyponym>
</concept>
```

Figure 7-21: XML segment for the concept “Panel”

7.7.3 Implementation for Effective Search Terms Capturing

The interface of effective search term capturing is separated from that of semantic context capturing. This is shown in Figure 7-22.

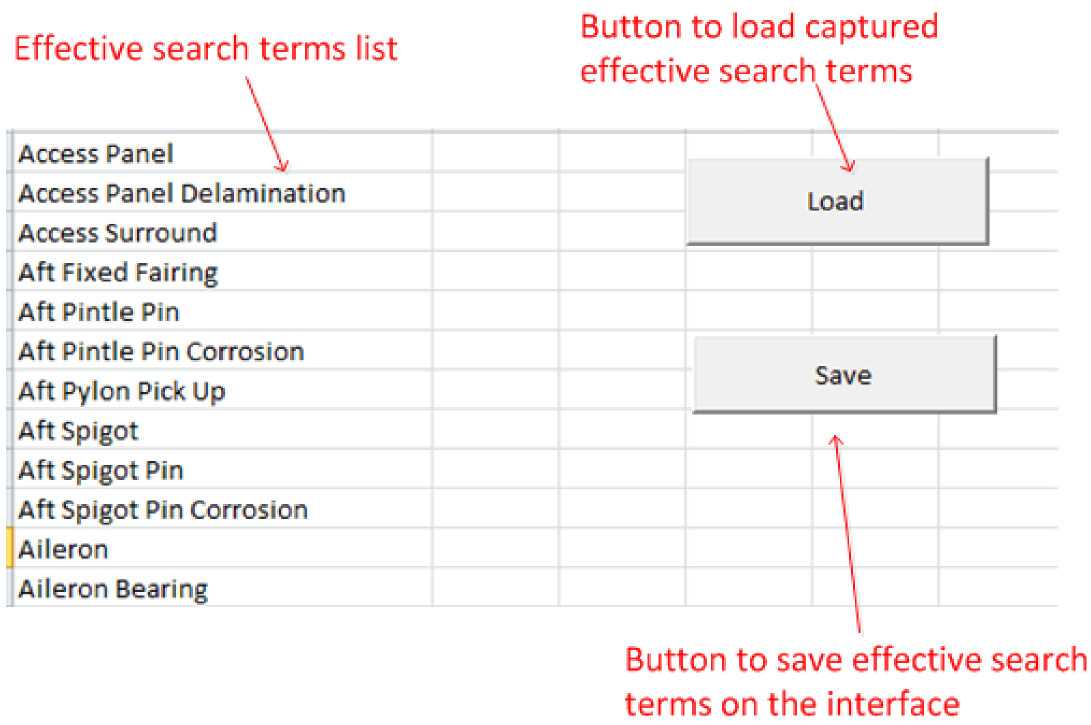


Figure 7-22: Interface for Effective Search Terms Capturing

As shown in the above figure, this interface consists of the following elements:

- **Effective search terms list**: All the effective search terms that are already captured will be displayed in this list. The user can modify this list on the spreadsheet interface to add, edit or remove entries.
- **Load button**: When this button is clicked, all the effective search terms that are already captured and stored in the *Context Model* will be loaded in the effective search term list in alphabetical order.
- **Save button**: When this button is clicked, all the effective search terms existing in the effective search terms list will be saved and stored in the *Context Model*.

```xml
<concept name="Effective Search Terms">
    <EST>Access Panel</EST>
    <EST>Access Panel Delamination</EST>
    <EST>Access Surround</EST>
    <EST>Aft Fixed Fairing</EST>
    <EST>Aft Pintle Pin</EST>
    <EST>Aft Pintle Pin Corrosion</EST>
    <EST>Aft Pylon Pick Up</EST>
    <EST>Aft Spigot</EST>
    <EST>Aft Spigot Pin</EST>
    <EST>Aft Spigot Pin Corrosion</EST>
    <EST>Aileron</EST>
    <EST>Aileron Bearing</EST>
    <EST>Aileron Hinge</EST>
    <EST>Aileron Hinge Bearing</EST>
```

Figure 7-23: XML scheme for Effective Search Terms

In Figure 7-22, examples of effective search terms are shown in the effective search terms list on the interface. The following figure, Figure 7-23, shows the corresponding XML section in the *Context Module* for these entries. As shown in this figure, a special <concept> tag with the name "Effective Search Terms" are reserved for the capturing and storing of effective search terms. Comparing to other <concept> tag as shown in Figure 7-21, this <concept> tag only contain one type of sub tag <EST>. Each instance of <EST> tag is used to capture an entry in the effective search terms list when the **Save** button is clicked.

7.7.4 Implementation for Search Terms Expansion

As illustrated in sequence diagrams in Figures 7-4 to 7-8, the search terms expansion functionality is activated automatically every time a repair case search takes place. This functionality allows the search term used in the search to be processed to identify if semantic concepts contained in the search terms are captured in the *Context Model*, and then performs search terms expansion based on the semantic context that is extracted. In the following text, the implementation details of search terms expansion are discussed using two "Search terms expansion scenarios": the first scenario focus on synonyms and acronyms, and the second scenario on hyponyms.

Search Terms Expansion Scenario 1: Expansion with Synonyms and Acronyms

The impact of the search terms expansion functionality on the search results is illustrated in Figure 7-24. The left side of this figure shows the search result for the search term "Corrosion MLG" *without* search terms expansion. On the right hand side, the search result of the same search term is shown *with* search terms expansion. As shown in this figure, when the search terms expansion functionality is not activated, the search results only contains repair cases with the exact term "Corrosion MLG" in the description. On the other hand, the search results with search terms expansion on the right contains wider selection. For example, the term "Corrosion" and "MLG" are not necessary in adjacent orders in the text. Additionally, the search result also contains repair cases with the term "Main Landing Gear" which has the acronym "MLG". In term of repair cases found, there are 16 repair cases in the search result without search terms expansion, as compare to 211 repair cases with search terms expansion.

Figure 7-24: Impact of Search Terms Expansion

The search terms expansion functionality is realised by firstly extracting the semantic context stored in the *Context Model* and secondly automatically generating Advanced Criteria Filtering based on what is extracted. In Figure 7-25, the XML segment in the *Context Model* for the concept "Main Landing Gear" is shown.

```
<concept name="Main Landing Gear">
    <synacr>MLG</synacr>
    <synacr>Landing Gear</synacr>
    <synacr>Leg</synacr>
</concept>
```

Figure 7-25: XML segment for the concept "Main Landing Gear"

When the search terms expansion functionality is activated, the *Search Module* extracts the semantic context shown above. This includes information in the <concept> and <synarc> tags. The extracted semantic context is then used to generate the following Advance Criteria Filtering setting in MS Excel, as shown in Figure 7-26 below:

Combine	Combine
* corrosion *	* Main Landing Gear *
* corrosion *	* MLG *
* corrosion *	* Landing Gear *
* corrosion *	* Leg *

Figure 7-26: Advance Criteria Filtering setting for the search term "Corrosion MLG"

By applying this filtering setting on the "Combine" field, the repair case search functionality is extend to include the term "corrosion" with different syntactic forms of the concept "Main Landing Gear".

Search Terms Expansion Scenario 2: Expansion with Hyponyms

Search terms expansion with hyponyms was implemented in a similar way to that of expansion for synonyms and acronyms: The *Search Module* firstly extracts captured semantic context from the *Context Model*, the Advance Criteria Filtering setting is then automatically generated in MS Excel to filter the repair cases, as specified in requirement 3.3.3 “Hyponym Expansion”.

The search terms expansion for hyponyms were specifically introduced to handle hyponyms for specific parts such as panel, ribs, spar and beams. The capturing of hyponyms for the concept “Panel” is shown in Figure 7-27. In this example, three hyponyms “Panel 1”, “Panel 2” and Panel 3” are captured, while the synonym “PNL” is captured.

```
<concept name="Panel">
    <synacr>PNL</synacr>
    <hyponym>Panel 1</hyponym>
    <hyponym>Panel 2</hyponym>
    <hyponym>Panel 3</hyponym>
</concept>
```

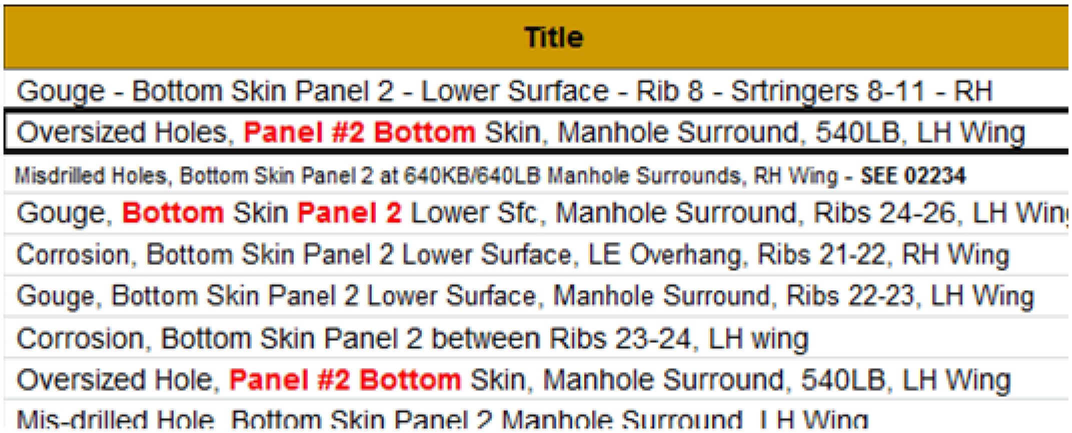
Figure 7-27: Hyponyms for the concept “Panel”

An example is presented here using the search term “Bottom Panel 2” to illustrate the implementation for expansion with hyponyms. When the search term “Bottom Panel 2” is processed, the *Search Modu*le identifies the term “Panel 2” is captured as a hyponym for the concept “Panel”, as shown in Figure 7-27. The *Search Module* then proceeds to extract semantic context related to the concept “Panel” which include the synonym “PNL”.

Combine	Combine
* bottom *	* Panel 2 *
* bottom *	* PNL 2 *
* bottom *	* PNL #2 *
* bottom *	* Panel #2 *

Figure 7-28: Advance Criteria Filtering setting for the search term “Bottom Panel 2”

In the next step, the *Search Module* expands the term “Panel 2” to include the synonym “PNL” for the concept “Panel”. Additionally, the *Search Module* also expand the term “Panel 2” to include two different convention of such hyponyms are expressed , one with the number “2” and another with “#” in front of “2”. As a result, the Advance Criteria Filtering setting is generated as shown in Figure 7-28. The repair case search result for the search term “Bottom Panel 2” is partly shown in Figure 7-29.



Title
Gouge - Bottom Skin Panel 2 - Lower Surface - Rib 8 - Srtringers 8-11 - RH
Oversized Holes, **Panel #2 Bottom** Skin, Manhole Surround, 540LB, LH Wing
Misdrilled Holes, Bottom Skin Panel 2 at 640KB/640LB Manhole Surrounds, RH Wing - **SEE 02234**
Gouge, **Bottom** Skin **Panel 2** Lower Sfc, Manhole Surround, Ribs 24-26, LH Win
Corrosion, Bottom Skin Panel 2 Lower Surface, LE Overhang, Ribs 21-22, RH Wing
Gouge, Bottom Skin Panel 2 Lower Surface, Manhole Surround, Ribs 22-23, LH Wing
Corrosion, Bottom Skin Panel 2 between Ribs 23-24, LH wing
Oversized Hole, **Panel #2 Bottom** Skin, Manhole Surround, 540LB, LH Wing
Mis-drilled Hole, Bottom Skin Panel 2 Manhole Surround, LH Wing

Figure 7-29: Search result of "Bottom Panel 2"

7.7.5 Implementation for Search Terms Suggestion

As illustrated in the sequence diagram in Figure 7-7, the search terms suggestion functionality is activated when the user starts typing in the search box, this functionality allows the search terms suggestion list to response to the textual content typed in by the user. The *Search Module* then retrieves the captured effective search terms from the *Context Module,* and displays effective search terms that contain the typed in content as search terms suggestions.

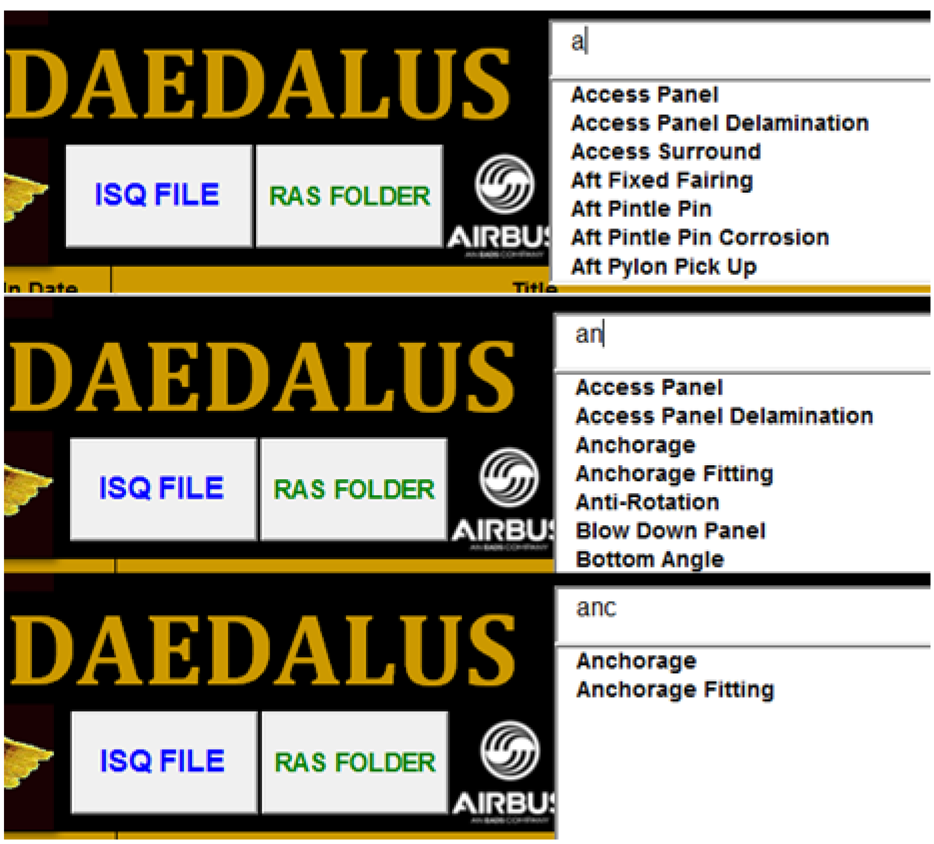


Figure 7-30: Display of Search Terms Suggestion

Figure 7-30 illustrates how such search terms suggestions are displayed. As shown in the top half of this figure, when the user types in the first character "a", the search terms suggestion list starting to populate search term with the letter "a". This list is initially large since many effective search terms would contain this single character. As the user proceeds with the typing, and types in the second character "n", the search terms featured in the search terms suggest list start to be narrowed down, as shown in the middle part of Figure 7-30. By the time the third letter "c" is typed in, the search terms suggestion list now shows only two search terms as suggestions, as shown in the bottom part of Figure 7-30. These are the only two captured effective search terms that contain the string "anc"

After the list of search terms suggestions become more relevant as shown in the bottom part of Figure 7-30, the user can choose the desired search terms suggestion by clicking on it, as shown in Figure 7-31. This will automatically fill the search box with the chosen search term and launch the repair case search.

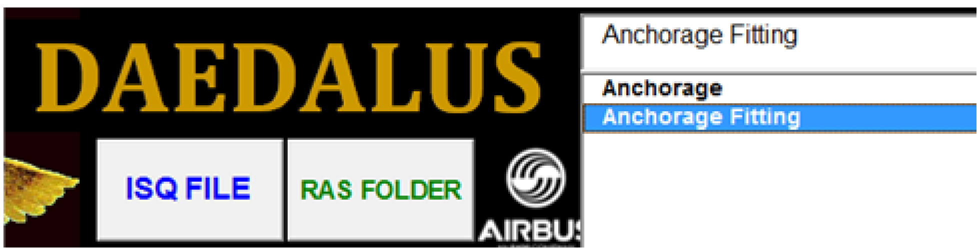


Figure 7-31: Selection of Search Terms Suggestion

7.7.6 Implementation for Usage Profiling

The Usage data is captured by the *Usage Profiling* module and then stored in a MS Access database. It contains information about In-Service engineers' activities to search and open repair case documents, and is composed of the following information fields in the profile database:

- *ID:* The Company IT login of an engineer.
- *Event:* An event is considered to be trigger when an engineer performs a certain action. When an event is trigger, an entry is created to indicate the types of event that took place. This include:
  - o Search: indicates a search has been performed
  - o Open Document: indicates a past repair case has been opened
- *Description*: This field is used to provide detailed description of a certain event.
  - o In the case of a "Search" event, this field is used to capture the search terms which the engineer used.
  - o In the case of an "Open Document" event, this field is used to capture the document identification number of the opened repair case document.
- *Number of Results:* This field is only used in the case of a "search event" to indicate the number of search result returned by Daedalus on the corresponding data base.
- *Date:* This field is used to capture the date which an event take place
- *Data Bases:* This field is used to capture the repair case database from which an engineer is searching. There are three repair cases databases: "A320 family", "Wide Body and Long Range" and "A380

A sample of the usage data is presented in the Table 7-7 below[12]:

ID	Event	Description	Number of Results	Search Date	Database
User1	Open Document	19120		29-May-12	A320 FAMILY ISQ DATABASE
User1	Search	aileron trailing edge	134	29-May-12	A320 FAMILY ISQ DATABASE
User2	Open Document	02403		29-May-12	A320 FAMILY ISQ DATABASE
User2	Open Document	03253		29-May-12	A320 FAMILY ISQ DATABASE
User2	Open Document	11370		29-May-12	A320 FAMILY ISQ DATABASE
User2	Search	Anchorage Fitting query	11	29-May-12	A320 FAMILY ISQ DATABASE
User2	Search	Anchorage Fitting inter	0	29-May-12	A320 FAMILY ISQ DATABASE
User2	Search	Anchorage Fitting	526	29-May-12	A320 FAMILY ISQ DATABASE
User3	Open Document	18871		29-May-12	A320 FAMILY ISQ DATABASE
User3	Open Document	20020		29-May-12	A320 FAMILY ISQ DATABASE
User3	Search	T/E overhang corrosion	624	29-May-12	A320 FAMILY ISQ DATABASE

Table 7-7: Example of Daedalus Usage Data

7.8 Summary

The repair cases search tool Daedalus was developed as an enabling platform for the experimental application of FBCC. This tool on one hand allowed in-service domain context to be captured, and on the other hand provided active and useful context aware functionalities to support and improve repair case search activity.

In this Chapter, the implementation details of Daedalus have been presented. The detailed requirements specification of Daedalus is presented in Section 7.3. These requirements outlined the core functionalities of Daedalus. These core functionalities were implemented in multi-phased agile development process, with the implementation of each phase focused on one of the following:

- Basic Repair Cases Search and usage profiling
- Semantic Context Capturing
- Effective Search Terms Capturing
- Search Terms Expansion
- Search Terms Suggestion

Modular based system architecture was applied to support these core functionalities with four interacting modules, namely the *Search Modules*, *Usage Profiling Module*, *Context Capturing Modules* and *Context Model.* Rationales for choice of development tools to

[12] User names are anonymised for confidential reasons.

implement each module are discussed in Section 7.5. MS Excel and MS Access were chosen as the basic platforms for software development for the *Search Modules*, *Usage Profiling Modules* and Context *Capturing Modules*, while a simple XML format were used to construct the *Context Model.*

Use cases for core functionalities are then presented in Section 7.6, providing detailed explanation on how various modules and non-system objects interact to bring about these core functionalities. Finally, technical implementation details on how each of these core functionalities is developed are presented in Section 7.7, with relations to the modules that are involved in each corresponding use cases.

Of note is the fact that as the system was being developed during its various phases, the in-service engineers started using the system actively. This was because it gave genuine benefit. This ensured the generation of a comprehensive range of usage data, as is discussed in the next chapter.

8 Empirical Study and Evaluation

During the experiment phase of this research, an experiment was conducted to capture and utilise context to support knowledge work. The overall details of this experiment are presented in Chapter 6 with repair case search of Airbus Wing ISS department as the engineering use case. The context aware system Daedalus was developed as discussed in Chapter 7. Daedalus served both as a tool to support daily repair case search, and as the enabling platform of the experiment. In this chapter, the empirical studies on experiment data and evaluation results are presented.

In Section 8.1, an overview of the experimental period is provided to outline key activities taken place. In Section 8.2, an overview on data generated from the experiment is presented. In the following Sections 8.3 to 8.7, various studies performed on the experiment data are analysed and presented. The main experiment deliverables are then reviewed in Section 8.8.

8.1 Main Experiment Events

The experiment started in April 2011. From this date, Daedalus was deployed within the Wing ISS department, and became available for all in-service engineers for the critical activity of past repair case searching. For the next 18 months, the "experiment" was carried out. This was to assess the effectiveness of the capture and utilisation of context of within the In-Service Support operation. As part of this experiment, the experimental application of **F**eedback **B**ased **C**ontext **C**apturing (**FBCC**) was undertaken following the three-staged process as described in subsection 6.5.2. The key events that took place are described in the following:

- **Usage Profiling**: This phase started immediately after the Daedalus' search functions was deployed in the In-Service environment after April 2011, and last for two months

  During this phase, the search function provided basic string search function to In-Service engineers. Meanwhile, the *Usage Profiling* module started to capture key information about engineers' search activities, as described in Chapter 7. The search history information captured during this phase was used as input to facilitate setup sessions during the *Context Setup* phase.

- **Context Setup:** The aim of this phase was to provide an initial captured set of *context elements* to enable the two functionalities to utilise context, namely that of search terms expansion and search terms suggestion. In-Service domain context was captured with three initial setup sessions as described below. The output of these three sessions are the versions 1, 2 and 3 of the *Context Model* , as seen in Tables 8-1 and 8-2 below.
  - *Concept & Relationship Sessions:* Two sessions took place in June 2011. The author and the repair case curator worked together to populate an initial set of concepts, relationships which were considered to be useful in repair case searching.

- *Effective Search Term Session:* This session took place in July 2011. Working in a manner similar to that of the *Context & Relationship Setup Sessions*, the author and the research curator collaborated to populate an initial set of effective search terms.

Additionally these sessions also served as an opportunity for the repair case curator to become fully familiar with the *Context Capturing* module of Daedalus.

- **Context Feedback:** After the Context *Setup* phase, both functionalities for context utilisation – search terms expansion and search terms suggestion - were activated to utilise the captured context. The *Usage Profiling* module of Daedalus continued to profile engineers' usage of Daedalus. This profiling activity lasted throughout the experimental period. During this period, the repair case curator checked the usage data regularly. By reflecting on the search terms used by the engineers, and also by using his own engineering knowledge, he performed regular updating on the *Context Model* via Daedalus' context capturing functionalities.

The main events of the experiment period are listed in Table 8-1 below:

Timeline	Key Experiment Event	FBCC phase
April – May 2011	- Daedalus was deployed with basic search function for repair case.	Usage Profiling
June Week 2, 2011	- Context setup session 1 to capture semantic context. - First version (V1) of the *context model* was retained after context setup session 1. - Search terms expansion functionality was activated.	Context Setup
June Week 3, 2011	- Context setup session 2 to capture semantic context. - Second version (V2) of the *context model* was retained after context session 2.	Context Setup
July Week 1, 2011	- Context setup session 3 to capture effective search terms. - Third version (V3) of the *context model* was retained after context setup session 3. - Search terms suggestion functionality was activated.	Context Setup
July Week2, 2011 **-** **September 2012**	- Repair case curator performed feedback to the *context model*. - Further 7 versions of the *context model* were retained during this period, as seen in Table 8-2.	Context Feedback
Oct, 2012	Empirical study and Evaluation activities started	Not Applicable

Table 8-1 Major events during the experiment period

Throughout this period, experiment data was generated from the usage of Daedalus and the application of FBCC. This is discussed in Section 8.2.

8.2 Experiment Data

During the experimental period, two types of experiment data were generated. Firstly, different versions of *context model* were retained at different points in time. Secondly, Usage data of Daedalus were captured by the *Usage Profiling Module*.

In this section, interpretations used to analysis the experiment data are addressed in subsection 8.2.1. The two types of experiment data are then discussed in subsections 8.2.2

and 8.2.3, respectively. A short overview on the various studies carried out on the experiment data is presented in 8.2.4.

8.2.1 Interpretations of Experiment Data

Before presenting the experiment data, it is important to explicitly clarify some of the interpretations applied during the experiment and the subsequent empirical studies. Although key research concepts such as semantic context, concepts and relationships are already addressed in Chapter 2, it is of beneficial to revisit them here with relation to both the generic meaning in this research and also the specific meaning in the experiment. These are outlined in Table 8-2 below:

Interpretation	Generic Meaning in this research	Specific Meaning in the experiment
Search Term	The term "search term" refers to words that users use to initiate information search on systems such as search engines.	The term "search term" is used to represent the key words that are used by engineers to initiate a repair case search using Daedalus. These were considered as "word forms" (Miller, Beckwith, Fellbaum, Gross, & Miller, 1990) of domain semantic context, as mentioned in Chapter 2. All search terms are captured in the usage data by the *Usage Profiling* module of Daedalus. Each search term can contained one or multiple words.
Context Model	The term "context model" refers to models created to represent the context of certain domain.	In this experiment, the term *Context Model* with italic form is specifically refer to the context model in XML format created to capture Wing ISS domain context during the experiment.
Context Element	The term "context element" has been addressed in the literature review as "*elemental information that combines and form what is perceived as context*".	In this experiment, context elements are equivalent to the XML elements that combine and form the *Context Model* in XML format. Each individual context element is therefore in XML format, and contains textual term captured under various XML tags, as specified in Section 7.7.
Semantic Context	The term "semantic context" has been addressed in the literature review as "context that originated from information semantics according to which information is interpreted"	In this experiment, the term "semantic context" referred concepts, synonyms/acronyms and hyponyms that are captured in the *Context Model* in the form of context elements, using XML tag as specified in Section 7.7. These were considered as "word meanings" of domain semantic context (Miller, Beckwith, Fellbaum, Gross, & Miller, 1990), as mentioned in Chapter 2.
Concept	The term "concept" refers to notions that are used within semantics of certain domain.	In this experiment, the term "concept" is referred to context elements in the *Context Model* with <concept> XML tag, as specified in Section 7.7. A term "X" is said to be "captured as a concept" if

		a context element with <concept> XML tag contains "X" as the textual content
Relationships	The term "relationships" refer to relationships between terms from a semantic sense.	In this experiment, the term "relationships" referred to context elements in the *Context Model* with corresponding XML tag, as seen in the follow entries in this table, and as specified in Section 7.7
Synonym/Acronym	The combined terms "synonym/acronym" is used to refer to terms that are of the same semantic meaning of another term in the form of synonym or acronym.	In this experiment, this combined term "synonym/acronym" is used to refer to context elements in the *Context Model* with <synarc> XML tag, as specified in Section 7.7. A term "X" is said to be "captured as synonym or acronym" of concept "Y", if a context element corresponding to concept "Y" contains a context element with <synarc> XML tag with the textual content of "X".
Hyponym	The term "hyponym" is used to represent terms that refer to semantic meaning included within that of another term.	In this experiment, the term "hyponym" is used to refer to context elements in the *Context Model* with <hyponym> XML tag, as specified in Section 7.7. A term "X" is said to be "captured as hyponym" of concept "Y", if a context element corresponding to concept "Y" contains a context element with <hyponym> XML tag with the textual content of "X".
Effective Search Term	The term "effective search terms" refers to a collection of search terms that were used commonly within the In-Service engineering population, and can lead to effective search results.	In this experiment, the term "effective search term" is used to refer to context elements in the *Context Model* with <EST> XML tag, as specified in Section 7.7 A term "X" is said to be captured as an effective search term" if a context element with <EST> XML tag contains "X" as the textual content.
Semantic Part	This term is not previously used in this thesis. Generically, this term refer to a certain part of a multi-word term with distinct semantic meaning. For example, the multi-word term "Skin corrosion" contains two semantic parts: "skin" refers to the cover of wingbox; "corrosion" refers to a damage type.	In this experiment, the term "semantic part" is used to understand how a given search term associate with semantic context captured in the *Context Model*. If a search term does not directly correspond with a concept, synonym/acronym or a hyponym, part or all of its semantic part might still be directly correspond with these context elements. This is further addressed in subsection 8.4.2.

8.2.2 Context Model Data

During the experimental period, the context of the In-Service domain was captured during different stage of FBCC and stored in the *Context Model*. 10 versions of the *Context Model* were retained, each representing a snapshot of the captured context at the time. The overall details of each version are given in the following Table 8-2. Further analysis on this data will be presented in Section 8.4.

Versions	Retained Date	Concepts	Synonym or Acronym	Hyponym	Effective Search Terms	Corresponding events & phases
V1	14/06/2011	47	83	28	0	Context Setup - Concept & Relationships Sessions
V2	21/06/2011	54	95	28	0	
V3	05/07/2011	65	103	28	207	Context Setup - Effective Search Term Setup Session
V4	22/07/2011	67	103	83	207	Context Feedback
V5	26/07/2011	67	106	85	212	
V6	09/08/2011	75	113	85	287	
V7	30/09/2011	79	119	85	300	
V8	14/03/2012	86	126	85	336	
V9	30/07/2012	90	131	85	343	
V10	22/09/2013	90	132	85	343	

Table 8-2: Overview of context elements in each *Context Model* version

8.2.3 Usage Data

During the experimental period, in total 76371 activity events were captured by the Daedalus *Usage Profiling* module. This includes 19225 "Search" events, and 56255 "Open Document" events. On average 185 searches took place per week and 632 repair cases opened. This is listed in Table 8-3 below

Statistic Type	Value
Total events captured	76371
Total number of search	19886
Total number of documents opened	56255
Average search per week	185
Average document openings per week	632

Table 8-3: Daedalus Usage Data Overview

As described in subsection 7.7.6, the data captured for each event contains the following information:

- *ID:* The company IT login of an engineer.
- *Event:* Two type of events are profiled: "Search" and "Open Documents"
- *Description*: This field is used to provide detail description of a certain event.
    - In the case of a "Search" event, this field is used to capture the search terms which the engineer used.

- o In the case of an "Open Document" event, this field is used to capture the document identification number of the opened repair case.
- *Number of Results:* This field indicates the number of search results returned by Daedalus on the corresponding data base.
- *Date:* This field is used to capture the data which an event take place
- *Data Bases:* This field is used to capture the repair case database from which an engineer is searching.

As mentioned in Section 4.3, the repair case document were stored in three repositories, this was according to the three aircraft product categories: SA (Single Aisle - A320 Family), WB&LR (Wide body and long range aircraft – A300, A310, A330 and A340), and A380. For the SA and WB & LR, each repair cases repository were further divided into two sections Pre-2004 (before 2004) and Aft-2004(after 2004) for legacy reasons. Figure 8-1 below gives a detailed breakdown on how the search events are distributed among this repositories and subsections.

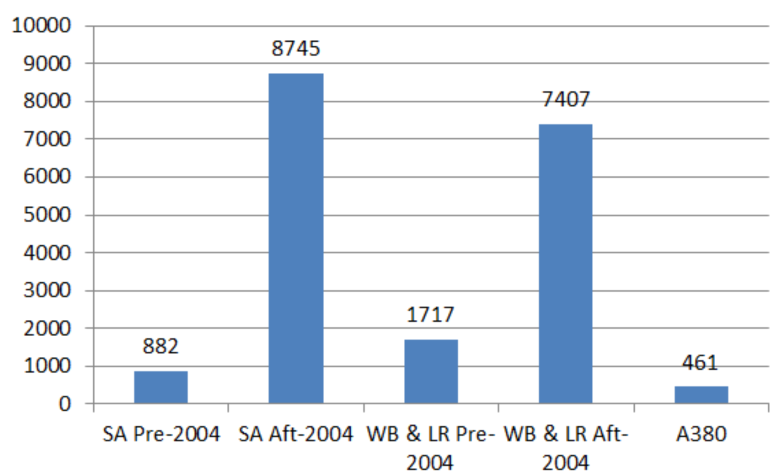


Figure 8-1: Distribution of search events among different repositories

More detailed studies on this usage data are presented throughout this chapter, as summarised below in subsection 8.2.4.

8.2.4 Studies on Experiment Data

The experimental data contained a lot of information about how Daedalus was being used, and how context was being captured and utilised. After the experimental period, the subsequent empirical study and evaluation activities took place in the form of a series detailed studies on these two types of experiment data. As mentioned in Section 6.6, the purpose of these activities was to generate the experiment deliverables that contributes to the research objectives. As outlined in the following:

- In-depth examination of Wing ISS domain semantic context.
- Evaluation of FBCC in term of cost-effectiveness in context capturing.
- Evaluation of Daedalus in terms of adoption level and impact on repair case search activity.

The studies were conducted as described in the following: Firstly, the examination of In-Service Support domain semantic context was conducted by performing an analysis of the search terms used by the engineers. This is presented in Section 8.3. Secondly, the evaluation of FBCC was conducted by analysing the context model data in two ways: firstly by analysing the nature of the captured context, this is presented in Section 8.4; and then by analysing how the captured context were being used utilised, this is presented in Sections 8.5 and 8.6. Finally, Daedalus was evaluated from two perspectives: the level of adoption, this is presented in Section 8.6; and the impact on repair case search activity, this is presented in Section 8.7.

8.3 Examination of In-Service Domain Semantic Context

When using Daedalus, In-Service engineers expressed their information needs by typing in search terms to search for past repair cases, as would be expected. However it is possible to interpret these search terms as a direct articulation of domain concepts used by the repair engineers. For this reason, the analysis of the search terms usage over a sustained period of time provides an opportunity to understand the nature of the context of this domain. This analysis is presented in the following sections: The usage distribution of search terms in each main product category are present in subsection 8.3.1; In subsection 8.3.2, comparison between most used search terms in different product categories are presented; In subsection 8.3.3, domain concepts that were captured in Daedalus' *Context Model* are compared to the standard Airbus vocabulary.

8.3.1 Usage Distribution of Search Terms

The set of search terms that were chosen for analysis were the textual search terms applied to the "Aft-2004" section of the SA and WB & LR and to A380. This was for the reasons that non-textual terms were mainly direct searches for specific repair cases with unique case ID, and did not contribute to the type of contextual information being captured in the *Context Model*.

The number of textual search terms subjected to analysis in each product category is illustrated in the following Table 8-4. Also shown is the total number of search event these search terms are associated with.

Product Category	Number of Unique Search Terms	Number of Associated Search
SA (Aft-2004)	2410	5127
WB & LR (Aft-2004)	1991	3808
A380	182	321

Table 8-4: Textual search terms to be analysis and associated search event

Due to the relatively short time that the A380 had been In-Service, the number of search terms for this category were smaller compare to that of SA and WB & LR. Details analysis for search terms for each product category is given in the following text.

The most used search term in the SA category have been used 63 times, while 70.26% of the 2088 search terms for this category were only used once. This distribution of search terms is displayed in the following Table 8-5 for the SA category:

Usage Frequency Group	Number of Search Term	Percentage of search terms	Number of associated search event	Percentage of associated search event
Used more than 20 times	21	0.87%	687	13.40%
Used between 10-19 times	49	2.03%	652	12.72%
Used between 5-9 times	132	5.48%	822	16.03%
Used between 2-4 times	500	20.75%	1258	24.57%
Used 1 time	1708	70.87%	1708	33.31%

Table 8-5: SA search terms analysis by search term usage frequency

In the above table, frequency groups are used to group search terms with different frequency of application. As shown above, the 21 most applied search terms, despite being 0.81% of all search terms used were associated with 687 or 13.40% of the captured search event.

In SA category, search terms that are used for more than 5 times correspond to 8.38% of all search terms used, but were associated with 42.15% of the captured search events for the SA product category. The following Tables 8-6 and 8-7 present the corresponding statistic for the WB & LR and A380 categories:

Frequency Group	Number of Search Term	Percentage of search terms	Number of associated search event	Percentage of associated search event
Used more than 20 times	12	0.60%	332	8.72%
Used between 10-19 times	29	1.46%	374	9.82%
Used between 5-9 times	98	4.92%	629	16.52%
Used between 2-4 times	415	20.84%	1036	27.21%
Used 1 time	1437	72.17%	1437	37.74%

Table 8-6: WB & LR search terms analysis by search term usage frequency

Frequency Group	Number of Search Term	Percentage of search terms	Number of associated search event	Percentage of associated search event
Used more than 20 times	1	0.55%	46	10.90%
Used between 5-9 times	8	4.40%	49	14.02%
Used between 2-4 times	47	25.82%	139	35.83%
Used 1 time	126	69.23%	137	39.25%

Table 8-7: A380 search terms analysis by search term usage frequency[13]

[13] In the A380 category, there is no search term in the “used between 10-19 times” frequence group.

In the LR & WB category, search terms that were used for more than 5 times corresponded to 6.98% of all search terms. They were associated with 35.06% of the search events. In the

A380 category, the most used search term alone was associated with 10.90% of the captured search event.

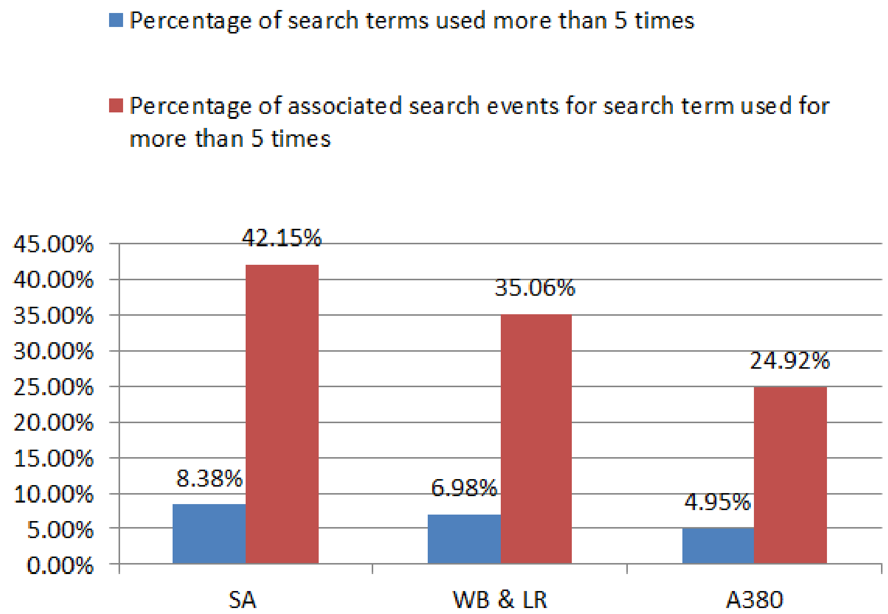


Figure 8-2: Percentage of search terms used for more than 5 times vs. Percentage of associated search event

This statistic for search terms used for more than 5 times in each product category, as opposed to the associated search event, is presented in the Figure 8-2 above. Based on this figure and the discussion above, the following observation is made:

Key Observation 1: The statistics above shows that a small percentage of search terms were associated with much larger percentage of search events.

8.3.2 Comparative Study on Search Terms and Domain Concepts

A comparison analysis is presented in the following text to identify the differences of search term usage in different product categories. Top 20 search terms for SA, WB & LR and A380 are listed in Table 8-8 below.

SA	WB & LR	A380
seal plate	Gear Rib	Intercostal
flap track fairing	Access Panel	Access Panel
corrosion	J-nose	rib
dry bay	MLG	corrosion
aileron	Leading Edge Access Panel	Delamination
Shroud Box	Corrosion	dent
wing tip	D Nose	GOOSE NECK
spigot	Rib 6	PAINT
Access Panel	wing tip	wing tip
riblet	Winglet	bush

gear rib	Delamination	d nose
lightning strike	lightning strike	IOFLE
Aileron Lightning Strike	MLG Corrosion	lightning
Overhang Corrosion	j nose	rotation
Delamination	Access Panel Delamination	521cb
Rib 10	Crack	621cb
hard landing	Erosion	Bush Rotation
pintle pin	hole 47	crack
manhole	Winglet Lightning Strike	panel
Stringer 11	leading edge	fastener

Table 8-8: Top 20 search terms for main product categories

Among the top 20 terms for the three product categories, 4 search terms are featured in each category. They are Corrosion*, Wing tip, Access Panel, Delamination*; 4 search terms are featured in two categories. They are *Gear Rib, Lightning Strike, D Nose, and Crack.* The rest 52 search terms are uniquely present in the top search terms for one category. This gives rise to the following observation:

Key Observation 2: search term usages were significantly different between different product categories.

For example, the search term "Intercostal"[14] has been used for 46 times since the A380 repair cases repository was set up in June 2011, it has however only been used 1 times in SA repository and never been used in the WB & LR repository. Of the 14 search terms that is unique in the A380 top search term list, 7 of them are used no more than once in WB & LR, and 8 of them are used no more than once in SA, as shown in the Table 8-9 below.

Search Terms	A380 Usage	WB & LR Usage	SA Usage
Intercostal	35	0	1
rib	7	3	2
dent	5	5	10
GOOSE NECK	5	0	1
PAINT	5	1	3
bush	4	10	12
IOFLE	4	0	0
lightning	4	6	10
rotation	4	1	1
521cb	3	0	0
621cb	3	0	0
Bush Rotation	3	11	6
panel	3	3	1
fastener	3	6	6

Table 8-9: Usage of top A380 search terms in SA and WB & LR

The potential implication for this is that, as new products come on stream, the required engineering context evolves significantly from that of old products. Context aware

[14] Intercosta is an aircraft part that connect two ribs for attachment of systems.

applications therefore need to be flexible enough to adapt regularly and capture context of evolving engineering designs to suit new engineering information need.

8.3.3 Comparison between In-Service Domain Concepts and Organisation Generic Context

Within Airbus, a glossary service called *Airbus LexiNet* is used to maintain organisational standard terms and abbreviations. At the time when this thesis was written, this glossary contained 2856 terms and 5902 abbreviations. In the other hand, the *Context Model* of Daedalus *contained* a list of concepts that are specifically applied to the Wing ISS domain. In the final version, the *Context Model* contained a total of 90 concepts, as shown in Tables 8-2 in Section 8.2.

Analysis was thus performed to investigate to what extent the Wing ISS domain context was covered by the organisational generic context. This was done by identifying how many concepts in the *Context Model* were included in Airbus LexiNet as terms or abbreviation.

Firstly, these 90 concepts are classified in to 6 categories, listed as the following:

- **Product Specific**: Concepts that refer to aircraft product or part of the product structure, for example “Access Panel”.
- **Damage Types**: Concepts that refer to specific damage types such aircraft sustained, for example “Corrosion”.
- **Incident Types**: Concepts that refer to particular type of incident which cause aircraft damage, for example “Miss drilled”.
- **Repair Specific**: Concepts that refer to repair related terms, methods and tools, for example “Repair Manual”
- **Mechanical**: Concepts that refer to generic mechanical parts, for example “Fastener”.
- **Generic:** General aerospace concept, such as “Airline”

Secondly, each concept captured in the *Context Model* was checked to see if it was included in Airbus LexiNet. The results are provided in the following Table 8-10:

Concept Category	**Number of concepts captured in *Context Model***	**Number of concepts included in Airbus LexiNet**
Product Specific	61	14
Damage Type	7	2
Incident Type	3	0
Repair Specific	5	4
Mechanical	12	3
Generic/Other	2	0

Table 8-10: Comparison between In-Service Concepts and Airbus Standard Glossary

In Table 8-10, the second column provides the number of concepts which were captured in the *Context Model*, that were classified in the corresponding concept categories. The third column provides the number of concepts, out of the concepts in the second column, which were included in Airbus LexiNet.

Key Observation 3: As illustrated in Table 8-10, large portion of Wing ISS domain concepts were not available within the organisational glossary. For the most significant concept category "Product Specific", only 14 out the 61 captured concepts were covered by Airbus LexiNet. For the secondly largest category "Mechanical", only 3 out of the 12 concepts were covered.

8.4 Analysis on Captured Context

In this section, detailed studies on the context captured in the *Context Model* are presented. The overall details of the 10 versions of the *Context Model* are presented above in Table 8-2. These different versions represented different snapshots of the captured context during different points of the experimental period. The progress of context capturing throughout the experiment period is presented in subsection 8.4.1. In subsection 8.4.2, study results will be presented to detail how top search terms were captured as *Context Element* in the *Context Model* during the experiment period.

8.4.1 Accumulation of Context Element

The 10 versions of the *Context Model that* were retained had growing number of context elements in the form of Concepts, Synonyms/Acronyms, Hyponym and Effective Search Terms. The growth of context elements is visualised in the following Figures 8-3 and 8-4.

Firstly, Figure 8-3 illustrated the growth of context element captured in *Context Model* across different versions. Key sessions in *Context Setup* phase *and* the *Context Feedback* phase are identified with corresponding versions.

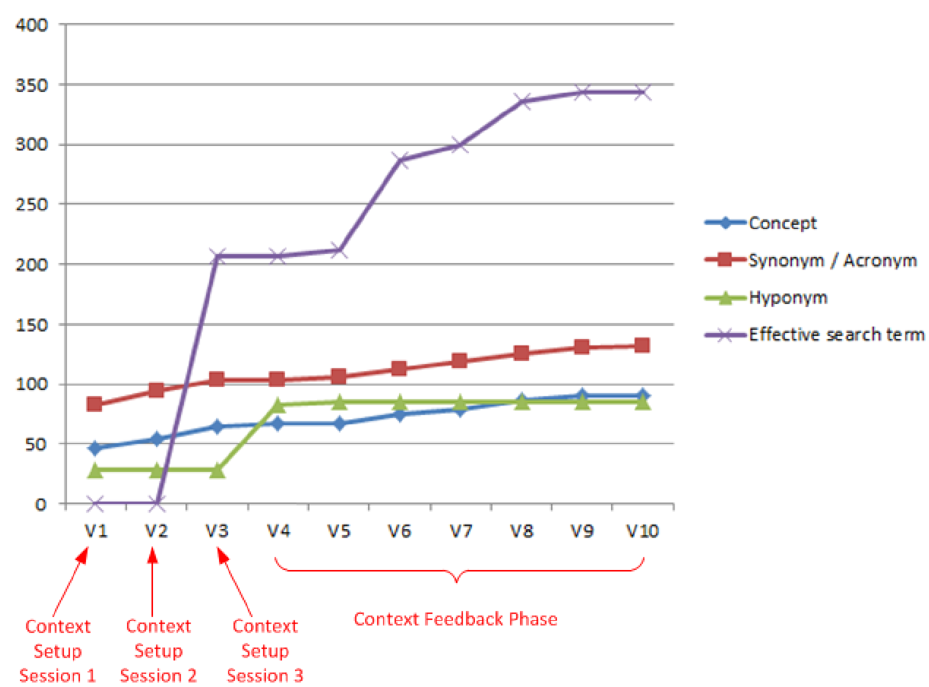


Figure 8-3: Accumulation of context element by different version of *Context Model*

As illustrated in Figure 8-3, sessions in the *Context Setup* phase contributed to large amount of context elements in the *Context Model*, resulted in steep growth. The accumulation curve then becomes more gradual during the *Context Feedback* phase. The gradual growth of context elements during the *Context Feedback* phase are more accurately illustrated in the following Figure 8-4 along the time axis.

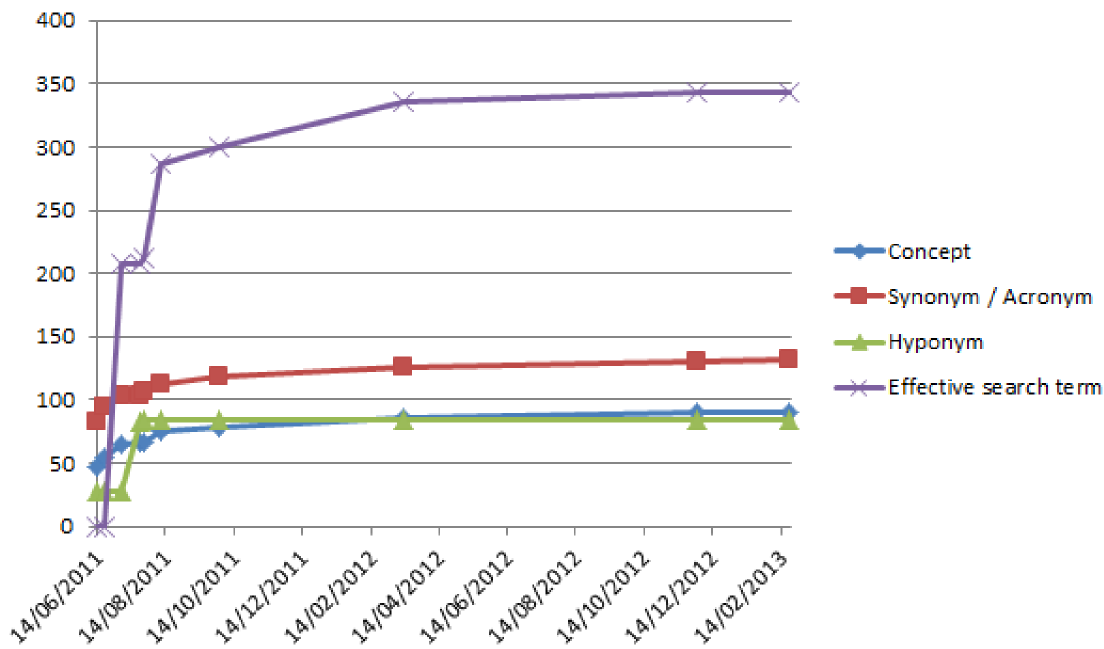


Figure 8-4: Accumulation of context element by time [15]

The following Figure 8-5 illustrates the proportions for each type of context elements captured during the *Context Setup* phase and the *Context Feedback* phase.

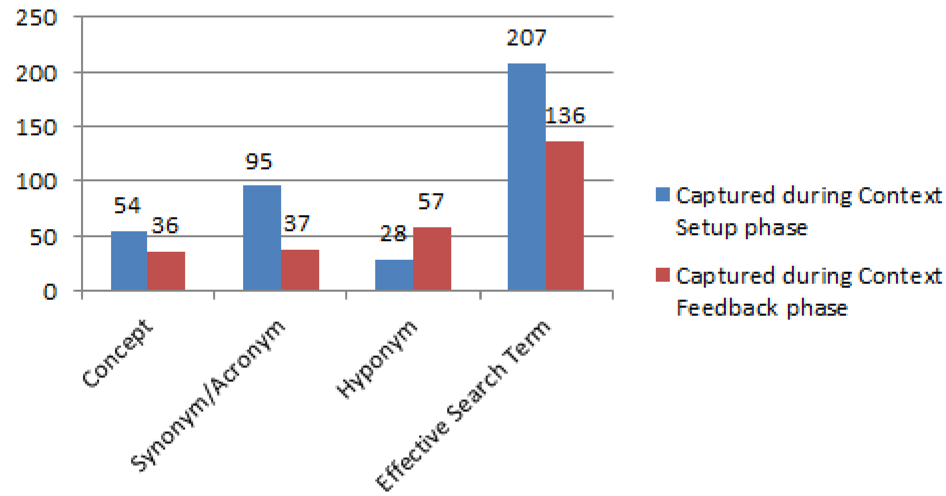


Figure 8-5: Contribution of context elements in the two phases of context capturing activity

Based on the information shown in Figure 8-5, the repair case curator's contribution to the *Context Model* during *Context Feedback* phase are: 40.00% of concepts (36 out of 90), 28.03% of synonyms or acronyms (37 out of 132), 67.06% of the hyponyms (57 out of 132) and 39.65% of effective search terms (136 out of 343). Overall, the context elements captured during the *Context Feedback* phase accounted for 40.92% (266 out of 650) of total amount of context elements. The overall distributions of captured context elements, in term of number of

[15] please note that in this figure the date value on the horizontal axis are not corresponding to the retained date of the *Context Model* versions.

context element captured, between these two phases are illustrated in the following Figure 8-6:

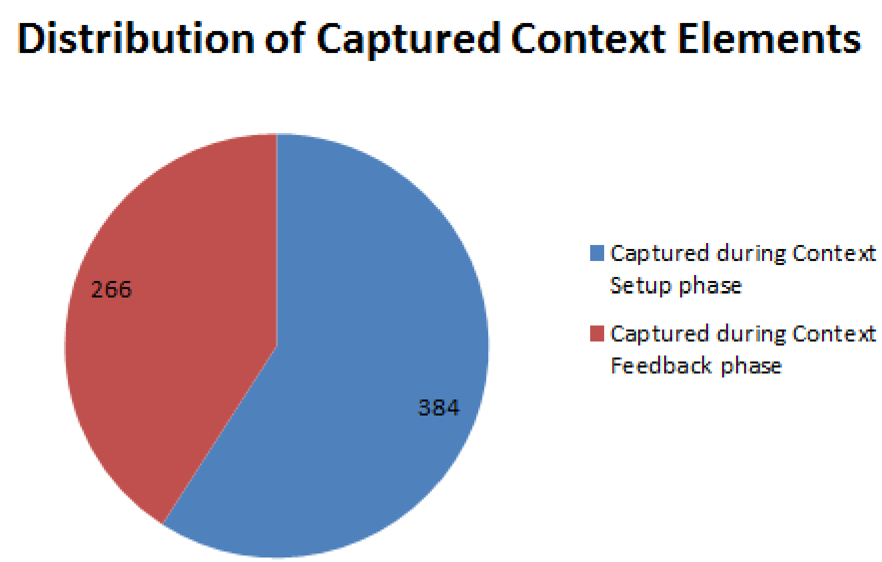


Figure 8-6: Distribution of captured context elements in the two phases of FBCC

Based on this statistic shown in Figures 8-5 and 8-6, the contribution of feedback based context capturing activity during the *Context Feedback* phase of FBCC were significant in relation to the total amount of context elements captured during the experimental period, despite the accumulation of context element become gradual during the *Context Feedback* phase. The following key observations were made:

Key Observation 4: The *Context Setup* phase made a large portion of initial contribution to the total amount of captured context. The accumulation rate of context element became more gradual during the *Context Feedback* phase, but showed the importance of this capability.

Key Observation 5: Despite the slower accumulate rate, the total amount of captured context elements during the *Context Feedback* phase was and continues to be significant.

8.4.2 Association between Captured Context and Top Search Terms

The search terms in the usage data provided an opportunity to understand the Wing ISS domain semantic context, since many of these search terms are direct representation of domain concepts or combinations of such concepts. The capturing of these search terms via the *Usage Profiling* module also allowed knowledge workers such as the repair case curator to analyse and compile effective search terms which help facilitate productive search activity.

The distribution of search terms is presented in subsection 8.3.1, highlighting that top search terms (search terms that are used most often) were used disproportionately more frequently than less used search terms. Meanwhile, comparative studies on top search terms between the three main product categories identified significant differences in search terms usage in each product category.

This observation provided the ideal information to evaluate the effectiveness of FBCC by studying the following:

- To what extent was the semantic context associated with the top search terms captured
- To what extent were these top search terms were captured as effective search terms

For this reason, a study was performed to investigate if and how the top 20 search terms in each product category were captured in the *Context Model*. In this study, the version 10 of the *Context Model* was used. A search term was considered "captured" if the associated domain concepts and relationships were captured or the search term itself is included as effective search terms. The detailed results of this study is illustrated in Figures 8-7 and 8-8, and summarised in the following text below.

Association between top search terms and semantic context captured

After studying the association between the top search terms and context elements in the *Context Model*, six types of associations were identified with relation to how a given search term was captured as semantic context. These are outlined in Table 8-11 below:

Code - Association	Description	Example
Con - Captured as concept	A search term is directly captured as a concept.	The search term "Wing Tip" is directly captured as the concept "Wing Tip".
NC - Not captured	A search term is not captured in the *Context Model*.	As seen in Table 8-12, the search term "Seal Plate" is not captured
Hyp - Captured as hyponym	A search terms is captured as a hyponym of a concept.	The search term "Stringer 11" is captured as a hyponym to the concept "Stringer".
Syn/Arc - Captured as synonym or acronym	A search term is captured as a synonym or an acronym of a concept.	The search term "Disbond" is captured as a synonym to the concept "Delamination". The search term "MLG" is captured as an acronym to the concept "Main Landing Gear"
Full-SP - All semantic parts captured	A search term would contain multiple semantic parts. Each of this semantic part would represent distinct semantic meaning. This association stands if all semantic parts of a search terms	The search term "MLG Corrosion" is composed of the semantic part "MLG" and "Corrosion. In this case, the term "MLG" is captured as a synonym for the concept "Main Landing Gear", while the term "Corrosion" is captured as a concept

	are captured in the *Context Model*.	
Part-SP - Some semantic parts captured	This association stands if some of the semantic parts of a search term are captured in the *Context Model.*	The search term “Flap Track Fairing” is composed of the semantic parts “Flap Track” and “Fairing”. In this case, the term “Flap Track” is captured as a concept, while the term “Fairing” is not captured in the *Context Model*.

Table 8-11: Associations between search terms and semantic context captured in the *Context Model*

Figure 8-7 below illustrates how the top search terms of each product categories were captured as semantic context in terms of the six associations types outlined in Table 8-11. A search term is considered to be “captured” if its association with the semantic context in the *Context Model* is of one of Con*, Hyp, Syn/Arc, Full-SP* or *Part-SP*.

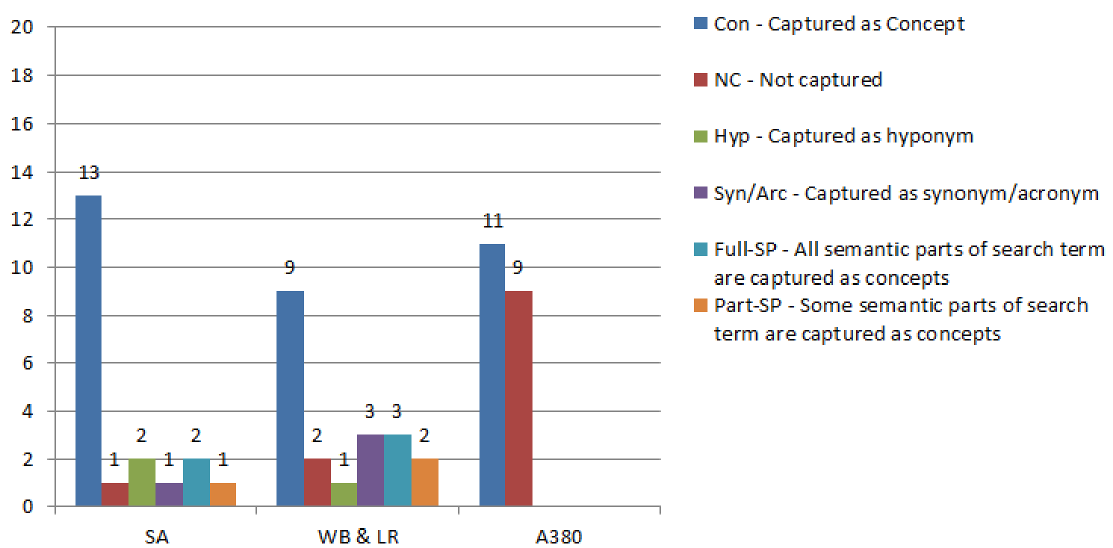


Figure 8-7: Capturing of top 20 search terms in *Context Model*

As seen in this figure, most top search terms in the SA (19 out of 20) and WB & LR (18 out of 20) categories are captured. Among the search terms that were captured, 13 top search terms for SA and 9 top search terms for WB & LB were directly captured as concept in the *Context Model*. Additionally, 6 top search terms of SA were captured as *Hyp*, Syn/Arc, Full-*SP* or *Part-SP*. The corresponding figure for WB & LR was 10.

As for A380, 11 of the 20 top search terms was captured as domain concepts, the other 9 top search terms were not captured. Compared to the more traditional product categories SA and WB & LR, the proportion of top search terms for A380 being captured as semantic context was lower.

The top search terms that were NOT captured in the forms of semantic context are given in following Table 8-11:

Product Category	Search Terms NOT Captured in *Context Model*
SA	seal plate
WB & LR	Winglet, Erosion
A380	Intercostal, GOOSE NECK, PAINT, bush, IOFLE, rotation, 521cb, 621cb, Bush Rotation

Table 8-12: Top 20 search terms that were not captured as *semantic context*

As shown in Table 8-12, the most searched for term "seal plate" for SA (as seen in Table 8-8) is a mechanical part, but this concept is not captured in *Context Model*. For the nine A380 top search terms that were not captured as semantic context, none them feature in the top 20 search terms for SA and WB & LR.

Capturing of top search terms as effective search terms

The capturing of top 20 search terms as effective search terms are visualised in Figure 8-8. The context capturing results for effective search terms in different product categories follow similar trend to that of semantic context - higher proportion of top search terms are captured in SA and WB &LR than that of A380.

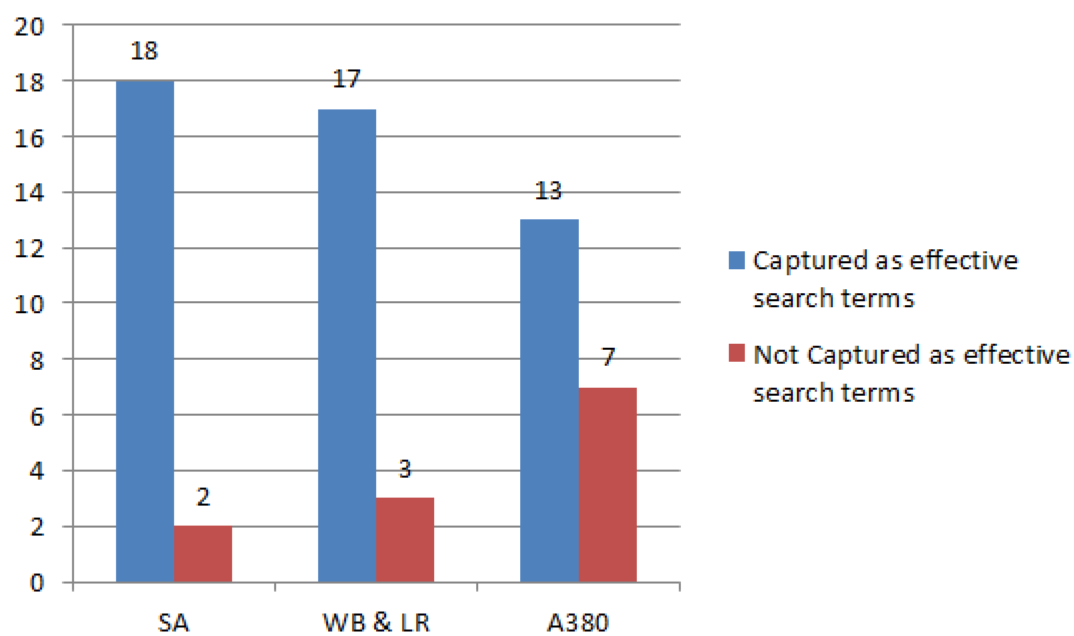


Figure 8-8: Capturing of top 20 search terms as effective search terms

Based on the above statistic, the following observations can be made:

Key Observation 6: It was evident that for traditional product categories, the majority of top search terms have been captured as at least one type of context element in the *Context Model*.

Key Observation 7: For new product category A380, the proportion of top search terms captured as *context element* was lower when compared to that of SA and WB & LR.

Key Observation 8: Some top search terms representing key in-service domain concepts were not captured in the *Context Model*.

8.5 Utilisation of Semantic Context

To evaluate the effectiveness of FBCC in context capturing, a key aspect is to understand how the captured context was utilised in repair case search activity. As introduced in Chapter 6 and Chapter 7, Daedalus was designed with the aim to support search and to explore how contextual information of the Wing ISS domain can be used to support repair case search activity. Two functionalities were implemented into Daedalus to realise this:

- Search Terms Expansion: Semantic context captured in the *Context Model* to be used to expand the search terms accordingly. This allowed semantically related concepts such as synonym, acronym, and hyponym to be considered during repair case search.
- Search Terms Suggestion: The effective search terms captured in the *Context Model* were used to provide a list of search terms to the engineers based on their typing.

The utilisation of captured context was evaluated by investigating the impact of these two functionalities on the repair cases search activity, and in particular, how the performance of these two functionalities change as context element accumulates within the *Context Model*. The evaluation for semantic context utilisation is presented in Section 8.5, while the evaluation for effective search terms utilisation is presented in Section 8.6.

In the following sections, the *Daedalus Search Simulator* – a search simulation tool created to evaluate the search terms expansion functionality is introduced in subsection 8.5.1, the evaluation results of the search term s is presented subsections 8.5.2 and 8.5.3.

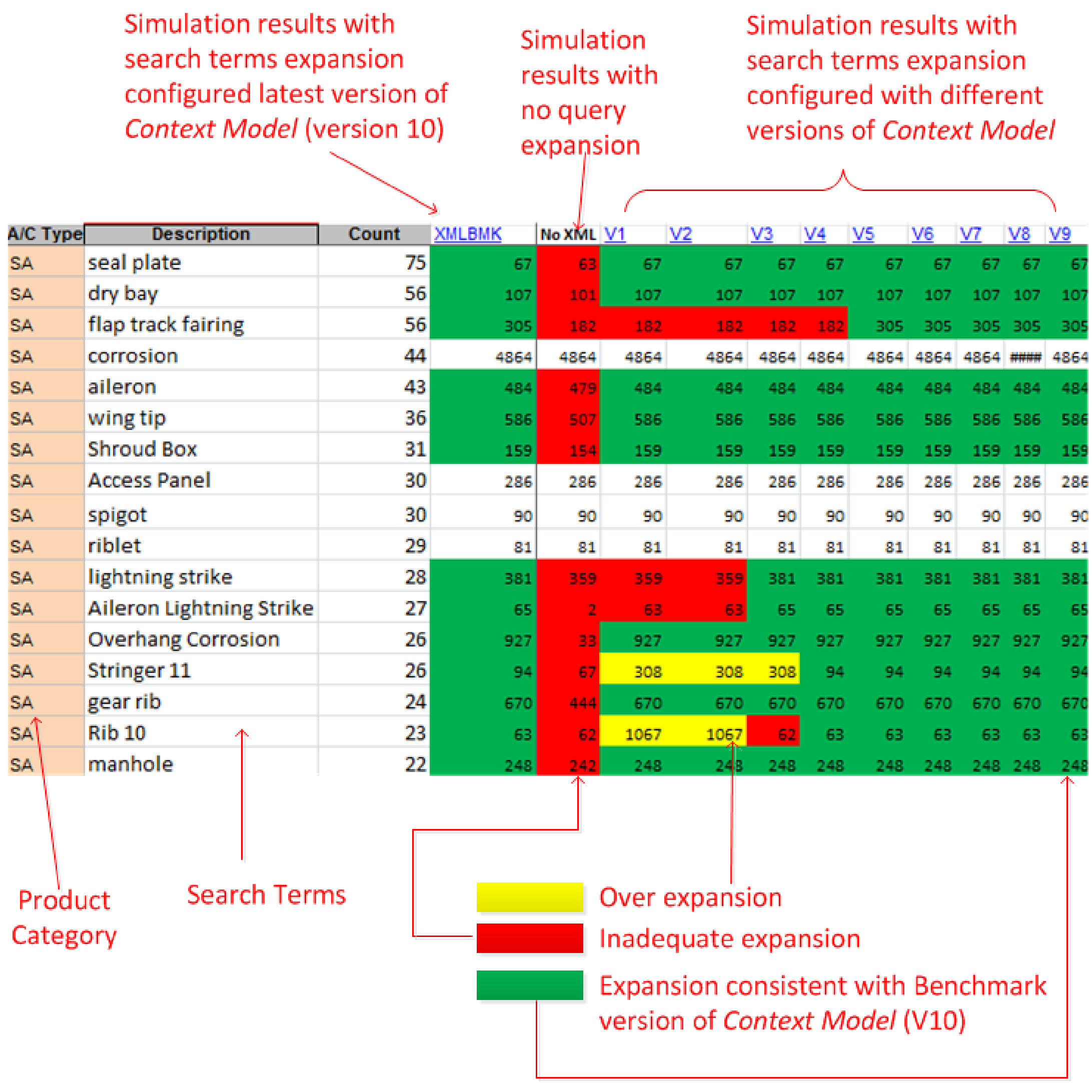
8.5.1 Simulating Repair Cases Searches

During the experimental period, in additional to capturing semantic context and effective search terms from usage history, the repair case curator used the search expansion functionality on a daily bases to search for repair cases.

While doing this, the repair case curator generated search results specifically to inspect 1) if any change on the *Context Model* was required; 2) if any previous changes were producing the desired effect; and 3) if new change in the *Context Model* would be required. This consistent inspection and feedback last throughout the experiment period, and formed the main driving factor behind the changes of the *Context Model* across time.

An assumption was made that the context captured in the *Context Model* evolved in the general direction of increasingly meeting the information needs of the Wing ISS Domain. Based on this assumption, during the evaluation exercises the author regarded the latest available version of the *Context Model* as the benchmark version during this evaluation exercise.

In order to clearly understand how the search terms expansion has impacted the search activities, the Daedalus Search Simulator (referred as "simulator in the following text) was created to simulate search activities recorded in in the Daedalus usage history. This simulator allowed the same search terms to be applied with different version of the *Context Model*, and allowed the difference in the simulation results – the number of returned repair cases – to be visualised with different colour.



A/C Type	Description	Count	XMLBMK	No XML	V1	V2	V3	V4	V5	V6	V7	V8	V9
SA	seal plate	75	67	63	67	67	67	67	67	67	67	67	67
SA	dry bay	56	107	101	107	107	107	107	107	107	107	107	107
SA	flap track fairing	56	305	182	182	182	182	182	305	305	305	305	305
SA	corrosion	44	4864	4864	4864	4864	4864	4864	4864	4864	4864	####	4864
SA	aileron	43	484	479	484	484	484	484	484	484	484	484	484
SA	wing tip	36	586	507	586	586	586	586	586	586	586	586	586
SA	Shroud Box	31	159	154	159	159	159	159	159	159	159	159	159
SA	Access Panel	30	286	286	286	286	286	286	286	286	286	286	286
SA	spigot	30	90	90	90	90	90	90	90	90	90	90	90
SA	riblet	29	81	81	81	81	81	81	81	81	81	81	81
SA	lightning strike	28	381	359	359	359	381	381	381	381	381	381	381
SA	Aileron Lightning Strike	27	65	2	63	63	65	65	65	65	65	65	65
SA	Overhang Corrosion	26	927	33	927	927	927	927	927	927	927	927	927
SA	Stringer 11	26	94	67	308	308	308	94	94	94	94	94	94
SA	gear rib	24	670	444	670	670	670	670	670	670	670	670	670
SA	Rib 10	23	63	62	1067	1067	62	63	63	63	63	63	63
SA	manhole	22	248	242	248	248	248	248	248	248	248	248	248

Figure 8-9: Daedalus Search Simulator

A screenshot of this simulator can be seen in Figure 8-9. As seen in this screenshot, the simulator simulate repair case search by using search terms that are retained in the usage history of Daedalus. The "Product Category" information identifies the corresponding repair cases database to which the search term was applied to when input by the engineers. By configuring the search terms expansion functionality with various version of *Context Model*, the simulator was able to simulate a series of repair case searches with any given search term. The column corresponding to each version of *Context Model* captures the number of repair cases returned by a given search, this is referred as the *simulation results* in the following text.

As shown in Figure 8-9, each row presented a series of simulated searches using the same search term, while each cell returned the result for result with corresponding version of the *Context Model*. A colour scheme with red, green and yellow was used to categorised the simulation results. the colour code was assigned automatically in the following setps:

1. The search terms expansion functionality was configured with the latest version of the *Context Model*(version 10), and the search was simulated with the search term. This simulation result was regarded as the benchmark result.
2. The search terms expansion functaionlity was then deactivated, and a simulated search wil be performed without any search terms expansions. this provide the search result with standard text search. This simulation result was regarded as the original result.
3. If the benchmark result was greater than the original result, then the benchmark result would be marked as green, and the the original result would be marked as red. Otherwise, both will be left with no color.
4. The search terms expansion functionality would now be configured with different versions of *Context Model*, and the simulator would simulate the search for each configuration. The following color coding logic was applied to each of the simulation result:
   - 4.1 If the number of repair cases in the simulation result was greater than that of the benchmarking result, then the simulation resulte would be marked as yellow.
   - 4.2 If the number of repair cases in the simulation result was smaller than that of the benchmarking result, then the simulation resulte would be marked as red.
   - 4.3 If the number of repair cases in the simulation result was equal to that of the benchmarking result, then the simulation resulte would be marked as green.

The simulator was used to perform two simulation exercises . The first exercise is presented in subsection 8.5.2, and the second exercise is presented in subsection 8.5.3.

8.5.2 Impact of Context Model during the Experiment

The first simulation exercise was to understand the search terms expansion functionality performed as the context elements were accumulated. This was achieved by performing search simulation with diffierent versions of the *Context Model*, as described in the following text.

In order to examine the impact of different versions of the *Context Model* on search terms expansion, repair case search simulation was performed on all the search terms that were used more than once for the SA prodcut category. According to the data provided in Table 8-5 in subsection 8.3.1, this included simulated searches for 702 search terms, representing 29.19% (702 out of 2410) of the textual search terms used and was associated with 66.69% (3419 out of 5127) of textual search events on the SA product category aft-2004 subsection. The portion of simulated search terms as related to all textual search terms, and the portion of associated search events as related to all textual search event, are illustrated in the following Figure 8-10:

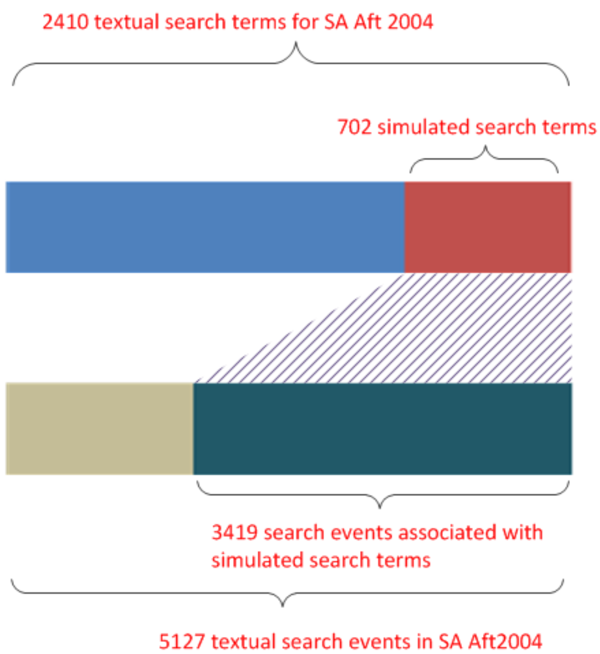


Figure 8-10: Mapping of simulated search and associated search events

As described in subsection 8.5.1, for each search term the following simulations results were generated:

- Benchmark simulation results with search terms expansion support by the latest version of the *Context Model.*
- Original results without search terms expansion
- Simulation results with search terms expansion supported by other versions of the *Context Model*.

The overall results with the colour coding scheme, as previously used, is presented in Table 8-12 below:

	Without Context Model	V1	V2	V3	V4	V5	V6	V7	V8	V9	Benchmark -V10
Inadequate Expansion Results	361	114	86	56	43	33	38	33	23	16	
Over Expansion Results		94	81	48	19	14	0	0	0	0	
Benchmark Expansion		167	206	259	300	315	323	328	338	345	361

Table 8-13: Simulated Search result with different versions of the *Context Model*

In this table, the "Inadequate Expansion Results" indicates query expansions that resulted in less expansion than the benchmark result - in this case the search returned less relevant cases than the benchmark result. To the contrary, the "Over Expansion Results" indicate query expansions that resulted in more expansion than the benchmark result - in this case the search returned results that were considered to be overall generalised.

Each change between different versions of the *Context Model* was made by the repair case curator. For example, the repair case curator, through monitoring the usage data, would decide that the search result for a certain search term was not ideal. He would then proceed to make appropriate changes to the *Context Model* via the context capturing functionalities of Daedalus.

The following example 9-11 provides an example for the term “flap track fairing”:

Example: Correcting inadequate expansion

A/C Type	Description	Count	XMLBMK	No XML	V1	V2	V3	V4	V5	V6
SA	flap track fairing	56	305	182	182	182	182	182	305	305

Figure 8-11: Inadequate expansion example

As shown above, it was determined that the captured context does not provide enough expansion for the search term “flap track fairing” in version 4 of *Context Model*. The change was then made in version 5, and provided the expansion result which was consistent with the benchmark result.

In this case, a change was made in the *Context Model* to include the term “Flap track” as a domain concept and associated hyponyms, and the following entry was created, as seen in Figure 8-12

```
<concept name="Flap track">
    <hyponym>Flap track 1</hyponym>
    <hyponym>Flap track 2</hyponym>
    <hyponym>Flap track 3</hyponym>
    <hyponym>Flap track 4</hyponym>
</concept>
```

Figure 8-12: Modification of inadequate expansion

Example: Correcting Over Expansion

In another example, the “Over expansion results” indicated query expansion that resulted in over generalised expansion – causing irrelevant repair cases to be returned. Similar to the above example, a change was made to provide better specified semantic context elements the *Context Model* will remove the over generalisation. The following example in Figure 8-13 provides an example for the term “Bottom Panel 3”

Description	Count	XMLBMK	V2	V3	V4	V5
Bottom Panel 3	12	99	874	444	99	99

Figure 8-13: Over expansion example

As shown above, it was determined that the captured context caused over expansion for the search term “Bottom Panel 3” both at version 2, and then again in version 3.

In this case, a change was made in version 2 to include the term “panel”, as synonym to “skin”, as shown in the “Version 2” part of Figure 8-14. These however caused over generalisation as the term “skin” is related to wider semantic content than the term “panel”. The returned result of 874 cases were much wider than what would have been related to “Bottom Panel 3”

For this reason, the term “panel” was instead captured as a concept in version 3, as shown in the “Version 3” part of Figure 8-14 this allowed the search function to allow panel as a concept while performing search expansion, and also search for the synonym term “PNL”. After this change, the number of repair cases returned becomes 444, as shown in Figure 8-13.

However, for the search term “Bottom Panel 3” concerned in this example, the change made above was still too generic since the engineer in this case would only be interested in repair cases related to “Panel 3”[16]. To accommodate for this specific need, hyponyms of the concept “Panel” were captured, as shown in the “version 4” part of Figure 8-14. This allowed the search function to expand the search term “Bottom Panel 3” appropriately since it can now recognised different hyponyms to the concept “Panel”.

Version 2

```
<concept name="skin">
    <synacr>Wingbox</synacr>
    <synacr>Wing box</synacr>
    <synacr>Wing skin</synacr>
    <synacr>Panel</synacr>
    <synacr>PNL</synacr>
</concept>
```

Version 3

```
<concept name="Panel">
    <synacr>PNL</synacr>
</concept>
```

```
<concept name="Panel">
    <synacr>PNL</synacr>
    <hyponym>Panel 1</hyponym>
    <hyponym>Panel 2</hyponym>
    <hyponym>Panel 3</hyponym>
</concept>
```

Version 4

Figure 8-14: Modification of over expansion

The evolution of semantic context captured in the *Context Model* across the 10 versions is visualised in Figure 8-15. As is evident from the this figure, there were no more “over-expanded” search terms as compared to the bench mark results after version 6 of *Context Model*. Also, at this point simulation results for 323 (as seen in Table 8-13) of the search terms provided became consistent with the benchmark results.

[16] It was decided that repair solution for “Bottom Panel 3” and “Top Panel 3” were similar, therefore the “Bottom” and “Top” term were not used to further specified the search terms expansion.

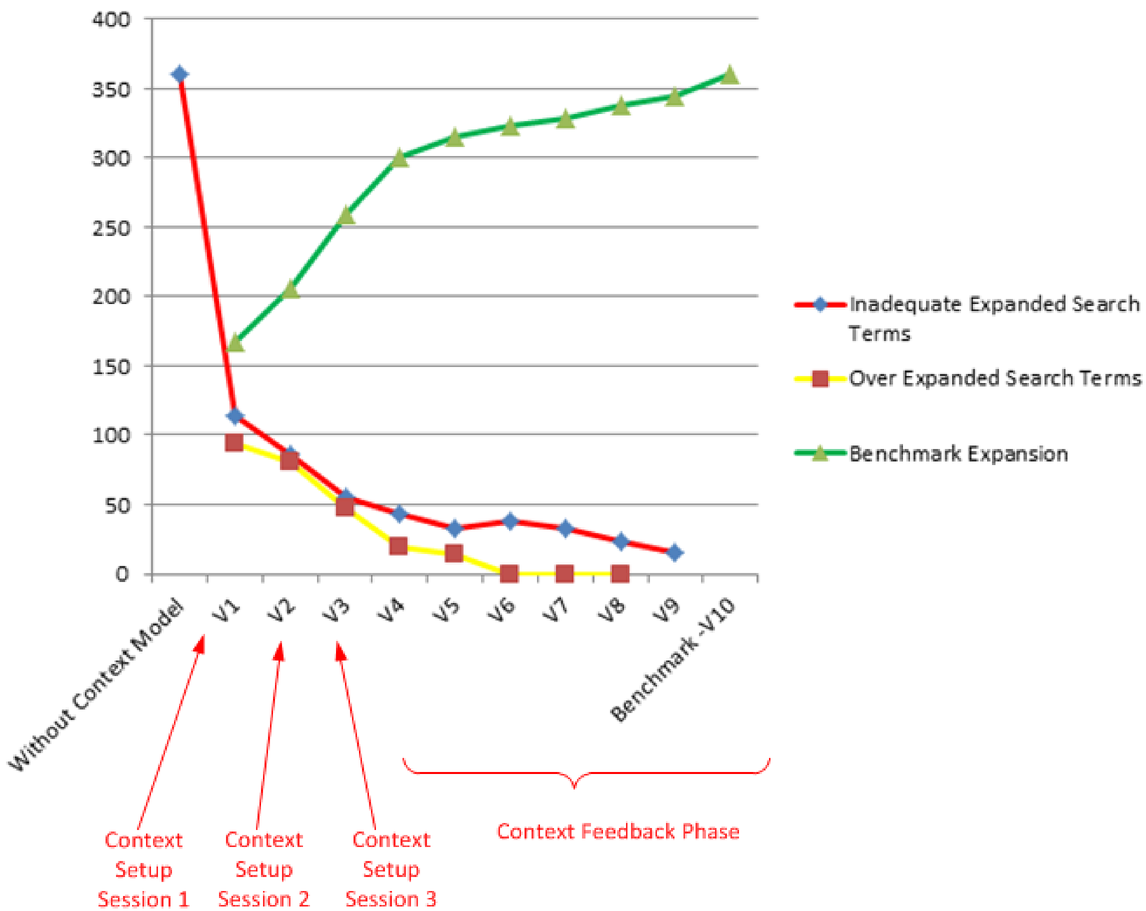


Figure 8-15: Evolvement of search expansion capabilities along different versions of *Context Model*

As shown in Table 8-2, this version of the Context *Model* was retained on 9th Aug during week 18 of the experimental period. Conversely, the number of inadequate expansions reduced more gradually after version 3. This matched with the starting of the *Context Feedback* phase of the context capturing, during which period the accumulation rate of context element in the *Context Model* became more gradual.

Based on these findings, the following key observation can be made:

Key Observation 9: Compared to the eventual benchmark result, significant degree of search terms expansion was in place within the first 20% (18 out of 89 weeks) of the total experiment period timespan.

Key Observation 10: The context captured during the *feedback stage* allowed the search terms expansion functionality to be fine tuned gradually throughout the experimental period.

Compared to the original result (simulation result without search terms expansion), 359 of the simulated search terms were semantically expanded when Version 10 of the *Context Model* was applied. These expanded terms, representing 14.9% of all textual search terms used in SA Aft 2004, and were associated with 2046 out of 5127 textual search events, representing 39.9% of all textual search events in the SA category. This is illustrated in the following Figure 8-16:

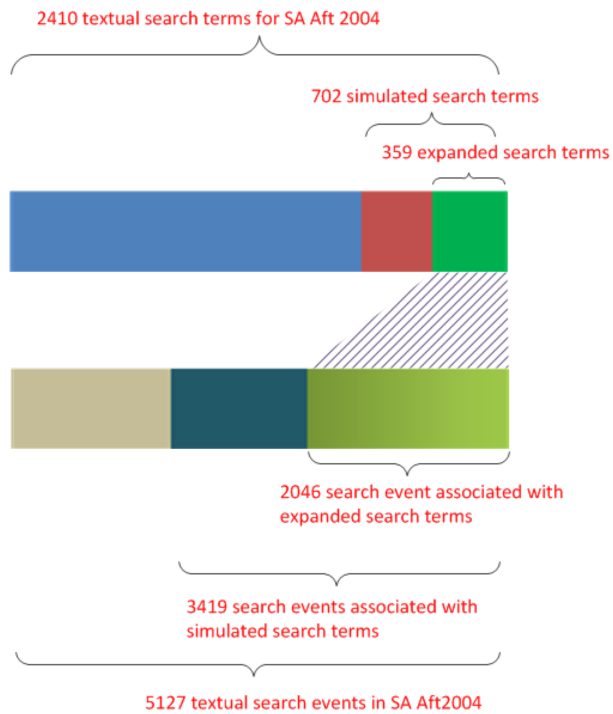


Figure 8-16: Mapping of expanded simulated search and associated search events for search terms used more than once

As illustrated in Figure 8-16, the relatively small proportion of expanded search terms was associated with comparatively larger proportion of search events. This indicated that the search terms expansions were more focussed on what can be thought of as popular search terms, this point will be further addressed in subsection 8.5.3.

8.5.3 Impact of Latest Version of the Context Model

The second exercise was to understand the final impact of the *Context Model* at the end of the experimental period. This was achieved by performing detailed analysis on the simulation search results with the latest version (version 10) of the *Context Model*.

In this exercise, all the textual search terms used on the SA and WB & LR product categories during the experimental period were used perform simulated searches with version 10 of the *Context Model*. Since the search terms were captured from the usage data, the simulated searches performed in this exercise reflect the search results would be provided if version 10 of *Context Model* was available from the beginning of the experiment. This exercise therefore gave an indication on how the search expansion capability would impact the daily repair case search operation.

Results from this exercise revealed that, for the SA Aft 2004 repair cases, 1073 out of 2410 search terms were semantically expanded, representing 44.52% of all the textual search terms used in the SA category. The total number of search events associated with these search terms was 2758, representing 53.8% of all textual search events in this product category

For the WB &LR Aft 2004 repair cases, 749 out of 1991 textual search terms were semantically expanded, representing 36.62% of all the textual search terms used in this category. The total number of search events associated with these search terms was 1727, representing 45.35% of all textual search event in this product category. These results are illustrated in the Figure 8-17 below:

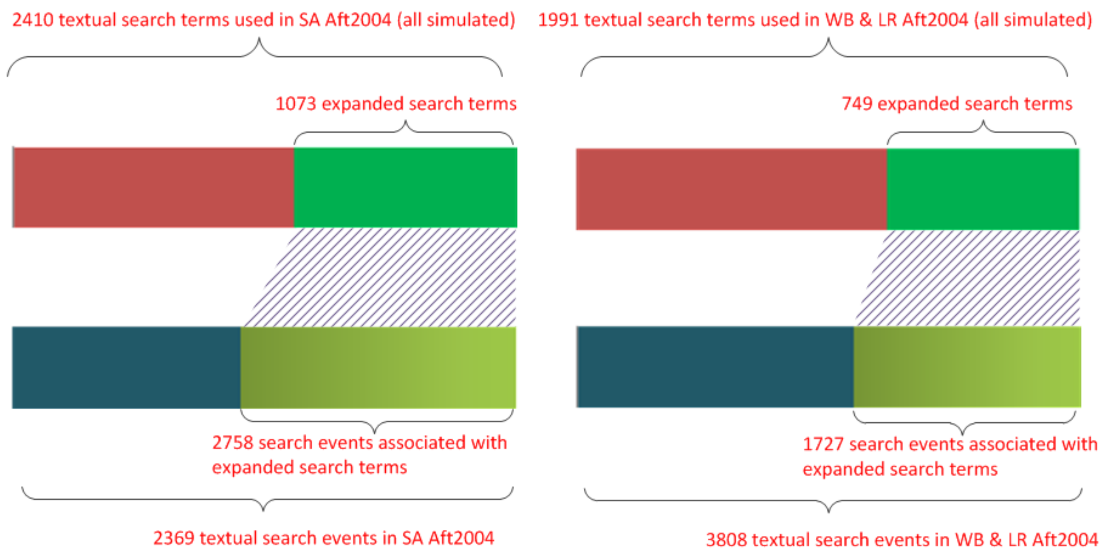


Figure 8-17: Mapping of expanded simulated search and associated search events for all SA and WB & LR search terms

For both product category, The semantic context captured in the *Context Model* were utilised to provide search terms expansion less than 50% of the search terms, and had impact on than 50% of the search events.

The overall result illustrated above were analysed with association to the search terms analysis results provided in Section 8.3. In particular, the analysis was performing using the same frequency group classification scheme used in Tables 8-5 and 8-6 in subsection 8.3.1. These results were then appended to the original tables to provide comparison, as shown in Tables 8-13 and 8-14.

The two columns added are the "Number of Expanded Search Terms" column which show the number of search terms that were expanded semantically within the corresponding frequency group. The "Percentage of Expansion" column indicates the percentage of search terms in the corresponding group that were expanded in this simulation exercise.

For example, in the first row of Table 8-13, out of the 21 search terms that were used more than 20 times for SA Aft2004 repair cases, 17 of these term were expanded in the simulation, and the percentage of expansion is 80.95%.

Frequency Group	Search Terms Number	Percentage of Search Terms	Number of Associated Search Events	Percentage of Associated Search Event	Number of Expanded Search Terms	Percentage of Expansion
Used more than 20 times	21	0.87%	687	13.40%	17	80.95%
Used between 10-19 times	49	2.03%	652	12.72%	33	67.35%

Used between 5-9 times	132	5.48%	822	16.03%	73	55.30%
Used between 2-4 times	500	20.75%	1258	24.57%	238	47.60%
Used 1 time	1708	70.87%	1708	33.31%	712	41.69%

Table 8-14: Search expansion by SA search terms usage frequency

Frequency Group	Search Terms Number	Percentage of Search Terms	Number of Associated Search Events	Percentage of Associated Search Event	Number of Expanded Search Terms	Percentage of Expansion
Used more than 20 times	12	0.60%	332	8.72%	9	75.00%
Used between 10-19 times	29	1.46%	374	9.82%	17	58.62%
Used between 5-9 times	98	4.92%	629	16.52%	50	51.02%
Used between 2-4 times	415	20.84%	1036	27.21%	167	40.24%
Used 1 time	1437	72.17%	1437	37.74%	506	35.21%

Table 8-15: Search expansion by WB & LR search terms usage frequency

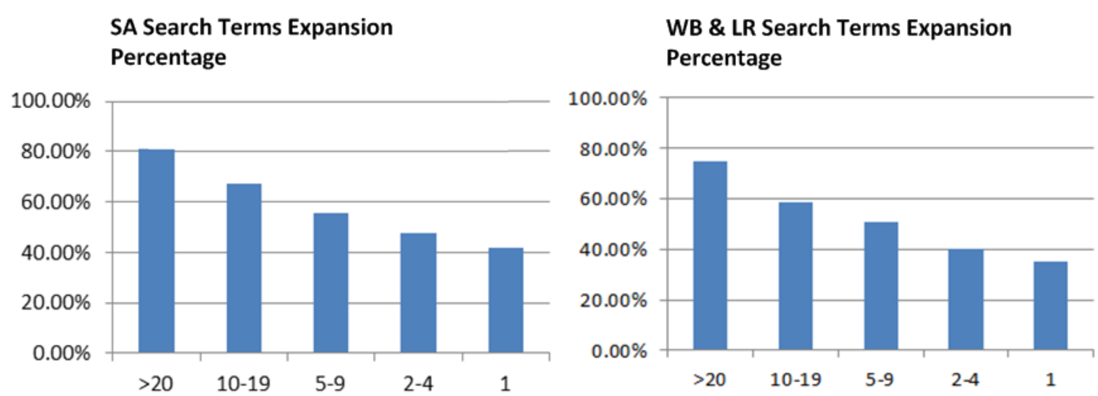


Figure 8-18: Illustration of search expansion percentage by search terms usage

The percentage of search terms expansion in the search simulations are illustrated in Figure 8-18 by frequency group. As shown in this figure, the percentage of search expansion were higher, interestingly, for the search terms that were more frequently used by the engineers during the experimental period. For the most used search terms, search terms that are used more than 20 times, 80.95% were expanded in the SA category while 75% were expanded in the WB & LR category. Thus the following observation can be made from this statistic:

Key Observation 11: The search terms expansion functionality was particular effective for search terms that were frequently used. It was evident that if a given search term was used more then it'd be more likely to be captured in the *Context Model*.

8.6 Utilisation of Effective Search Terms

343 of effective search terms were captured in version 10 of *Context Model*. These captured search terms were used to facilitate search terms suggestions based on the engineers' input. The analysis of the usage of these search terms is presented in this section.

This analysis was conducted by understanding how the various engineers responded to the search terms suggestions. In particular, statistics were gathered to reveal how often the search event was initiated by engineers picking the term from the search terms suggestion list as seen in Figure 8-19, as opposed to typing the term in its entirety.

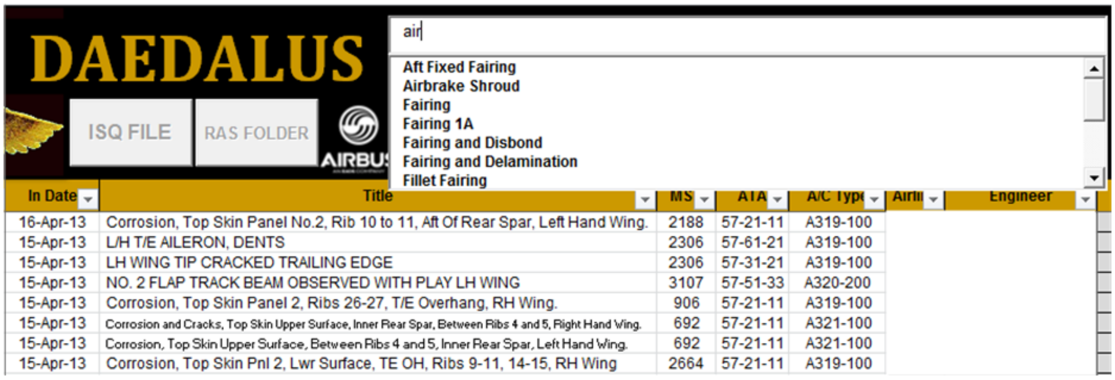


Figure 8-19: Example Search Terms Suggestions List

8.6.1 *Data collection*

In order to understand how the effective search terms were used via the search terms suggestion function, the following relevant information was extracted from the usage history:

- "Click Count": The amount of search events initiated by "clicking" on a given search term.
- "Total Count": The total amount of search events associated with the given search term.
- "C/T Ratio": The percentage of the search events initiated by clicking on a given search term. This is calculated by dividing the "**C**lick Count" by the "**T**otal Count" of a given search terms, and expressing the result using percentage - hence the name "C/T Ratio".
- "Length": The length of the search terms string in number of characters.

As an example, the 20 search terms with highest "Click Count" are provided in Table 8-15. In another word, these are the most used search terms suggestions.

Repair Domain Profile	Click Count	Total Count	C/T Ratio
Flap Track Fairing	55	70	78.57%
Access Panel	47	79	59.49%
Gear Rib	44	98	44.90%
Seal Plate	41	93	44.09%
Lightning Strike	39	55	70.91%
Leading Edge Access Panel	38	41	92.68%
Pylon Reinforcing Plate	35	39	89.74%
Access Panel Delamination	34	35	97.14%
Aileron	34	58	58.62%
Delamination	32	51	62.75%
Aileron Lightning Strike	31	31	100.00%
Manhole Surrounds	31	35	88.57%
Gear Rib Replacement	27	28	96.43%

Aft Pintle Pin	26	31	83.87%
Shroud Box	26	52	50.00%
Bottom Skin Manhole	25	25	100.00%
Pylon Systems	25	30	83.33%
J-Nose	25	37	67.57%
Overhang Corrosion	24	36	66.67%

Table 8-16: Effective search terms with top Click Count

8.6.2 Usage Analysis of Effective Search Terms

After collecting usage data of the search terms suggestion capability, the following detailed analysis can be made:

- General usage of effective search terms
- Analysis based on the “C/T Ratio” for search term with “Click Count” bigger than 1
- Analysis based on the length of search terms

General usage of effective search terms

Out of the 343 captured effective search terms, 299 search terms had been used by the engineers (i.e. Total Count > 0)); 259 search terms that had been clicked on appeared in the suggestion list (i.e. Click Count >0). Figure 8-20 illustrates the distribution of these search terms by different level of “Total Count” and “Click Count”. For example, this indicates that there were 11 search terms which have been selected between 30 to 49 times when they appeared in the suggestion list. While there are 19 search terms that were used between 30 to 49 times in total.

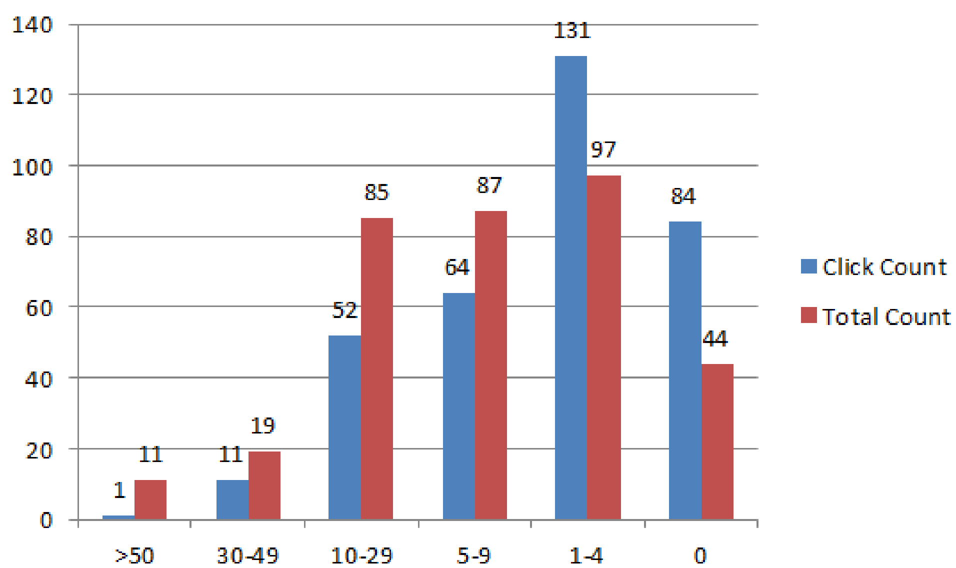


Figure 8-20: Effective search terms distribution by Click Count and Total Count

According to this figure, among the 343 search terms that were captured as effective search terms, 44 had never been used by the engineers during the experimental period. Based on this, the following key observation is made:

Key Observation 12: Some search terms (44 out of 343) were captured as effective search terms despite not having been used by the engineers at all.

Analysis based on the "C/T Ratio

Figure 8-21 below illustrates the distribution by different level of "C/T Ratio" for all effective search terms which were clicked on by the engineers when they appeared in the suggestion list. In this figure, the "0" column denotes effective search terms that have been shown BUT have not been chosen from the suggestion list. The "NA" column denotes effective search terms that have not been shown in the suggestion list during the experimental period.

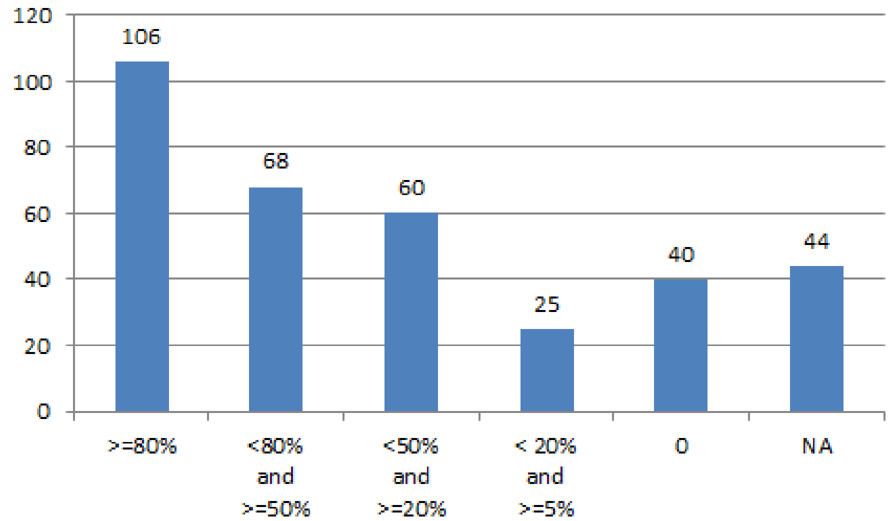


Figure 8-21: Effective Search Terms C/T Ratio Distribution

According to this figure, on average the "C/T Ratio" for effective search terms is 55.73%, indicating they were chosen by the engineers more often than not. As shown in this figure, 106 of the captured search terms were chosen in more than 80% of situations when provided as suggestions, while another 68 were chosen in more than 50% of the occasions. Based on these statistics, the following key observations are made:

Key Observation 13: The overall usage level of search suggestion was significant during the experimental period, on average, engineers were more likely to use search suggestions when they appeared.

Key Observation 14: 40 of the effective search terms were not clicked on despite being suggested to the engineers.

Analysis based on the length of effective search terms

Table 8-16 provides details on the C/T ratio for effective search terms of different length:

Length	Number of Search Terms	C/T Ratio
>20	42	90.38%
15-19	52	81.51%
10-14	72	62.35%
5-9	81	46.08%
<5	13	37.57%

Table 8-17: Effective search terms C/T Ratio by length

The C/T ratio of search terms of different length is also shown in Figure 8-22:

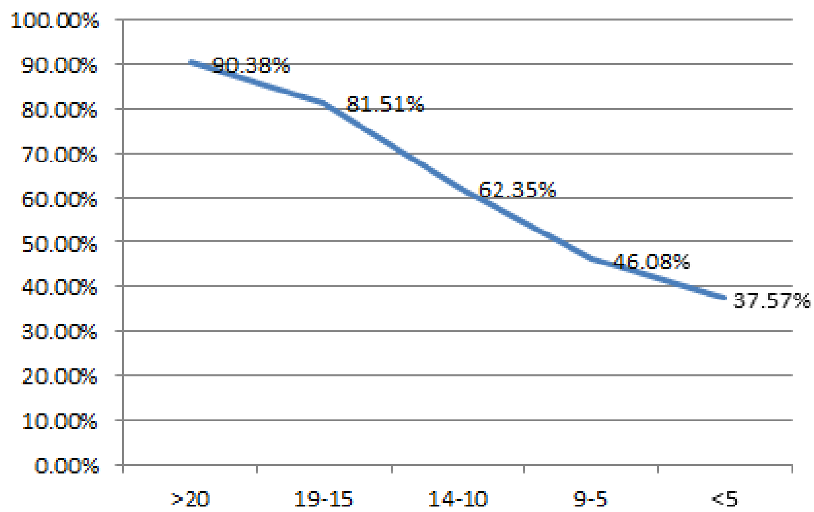


Figure 8-22: Illustration of effective search terms C/T radio by length

Based on Table 8-16 and Figure 8-22, for search terms that contain more than 20 characters, in 90.38% of circumstances the search terms suggestions were chosen by the engineers. For search terms longer than 10 characters, the search suggestions were more likely to be chosen. Therefore the following observation was made:

Key Observation 15: It was evident from this table that search suggestion for longer search terms are more likely to be used by the engineers.

8.7 Adoption Level and Impact of Daedalus

The adoption level of Daedalus was evaluated by analysing the general usage by In-Service engineers during the experimental period. This is presented in subsection 8.7.1. The impact of Daedalus on repair case search activities was evaluated by analysing engineers' behaviour in searching and opening repair cases during the experimental period. This is presented in subsection 8.7.2

8.7.1 Adoption Level of Daedalus

The adoption level of Daedalus was evaluated by the analysing the usage data with the following perspectives:

- General usages of the search function by In-Service engineers.
- Distribution of top 100 users by locations and by engineering disciplines

These analyses are presented in the following:

General usage of the search function by In-Service engineers

Figure 8-23 shows the search usage for each completed 12-week period in which Daedalus was used. As show in this figure, after the search function is introduced, the usage number climbs from the 1st 12-week period, and are above the 2200 consistently threshold for the last 4 12-week periods.

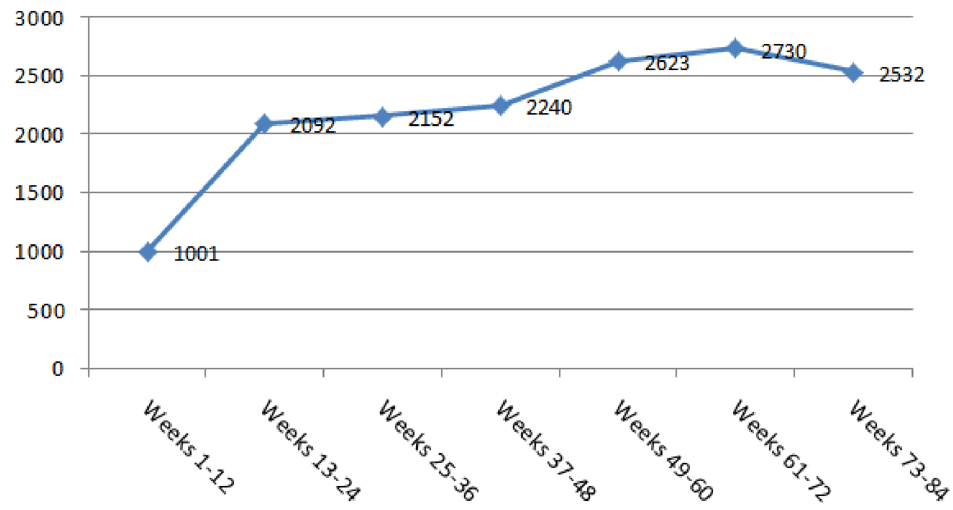


Figure 8-23: Number of Searches per 12-week period

Based on the overall usage statistic presented here, the following observation can be made:
Key Observation 16: Usage of Daedalus search function had been consistent at a significant level while rising throughout the majority of the experiment period.

Distribution of top 100 users by location and by engineering discipline

It was not feasible to determine engineering discipline background and location for individual - there were more than 200 engineers used Daedalus throughout the experiment, and many of these engineers had since left the department. Instead, the author performed interviews with Wing ISS Department managers to determine the engineering discipline of top 100 users. The results are shown in the following figures, giving rise to key observations 17 and 18:

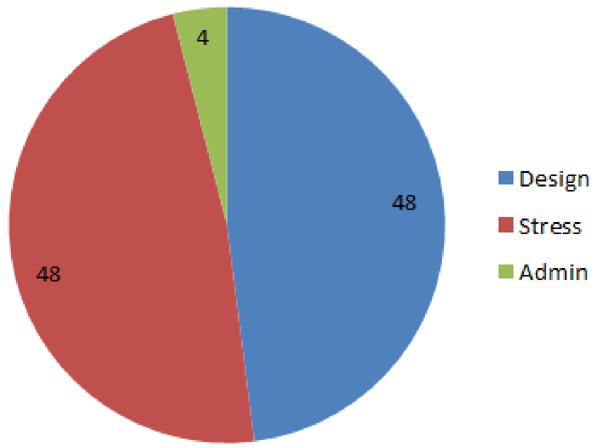


Figure 8-24: Distribution by disciplines of top 100 users

Key Observation 17: Based on the statistics shown in Figure 8-24, Daedalus was being evenly used between the main engineering disciplines in the Wing ISS department.

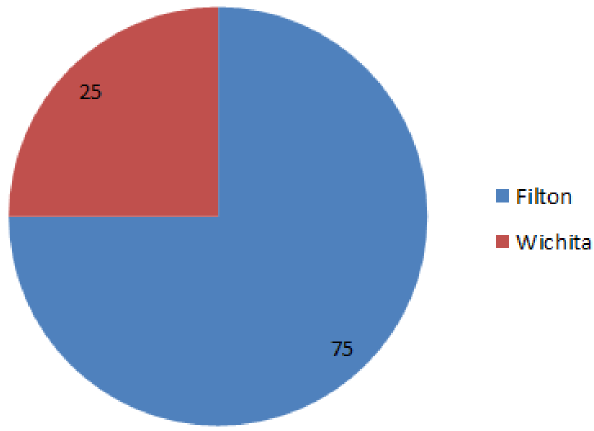


Figure 8-25: Distribution by top 100 users' locations

Key Observation 18: Based on Figure 8-25, both engineers in the UK and US were using the tools. The higher number for Filton was expected as the UK team had been bigger.

8.7.2 Impact of Daedalus on Repair Case Search Activity

The impact of the Daedalus on repair case search activity was evaluated by analysing engineers' behaviour in search and open repair cases during the experimental period. It was decided not to sample the performance of individual engineers. Instead, the ratio between search event and document open event were calculated.

This is to understand, on average, if less repair case documents were opened per search event at the end of the experiment. The author made the reasonable assumption that, if during an 18 months period with more than 200 users, fewer documents were opened per search, and then the application of Daedalus would have provided time saving benefit to the Wing ISS department. The result of the study is presented in the following text.

S/O Ratio

The Search/Open(S/O) ratio was used to represent the ration between search events and document open events for individual or a group of users. An example is given in the following:

- An S/O ratio of 50% indicates that number of search events equates to 50% of the number of document open events.

Based on the above, the S/O ration can be used to measure how many documents a user need to open to identify relevant past repair cases after a search is carried out. A high S/O ration would represent that a smaller amount of documents opened, and therefore less time spending on understanding information.

According to usage data, 203 engineers used Daedalus during the experimental period. Table 8-17 below shows the top 20 users in terms of search performed, open document. For each engineer, the total of the two events and the S/O ration are also shown.

ID	Open Document	Search	Total Events	S/O Ratio
User1	3210	40	3250	1.25%
User2	2787	258	3045	9.26%
User3	2512	0	2512	0.00%
User4	1878	412	2290	21.94%
User5	1439	524	1963	36.41%
User6	1513	341	1854	22.54%
User7	1588	143	1731	9.01%
User8	685	848	1533	123.80%
User9	1036	346	1382	33.40%
User10	881	378	1259	42.91%
User11	800	458	1258	57.25%
User12	596	608	1204	102.01%
User13	910	277	1187	30.44%
User14	770	404	1174	52.47%
User15	986	187	1173	18.97%
User16	812	360	1172	44.33%
User17	602	524	1126	87.04%
User18	424	621	1045	146.46%
User19	560	471	1031	84.11%
User20	950	5	955	0.53%

Table 8-18: Top 20 users with S/O Ratio

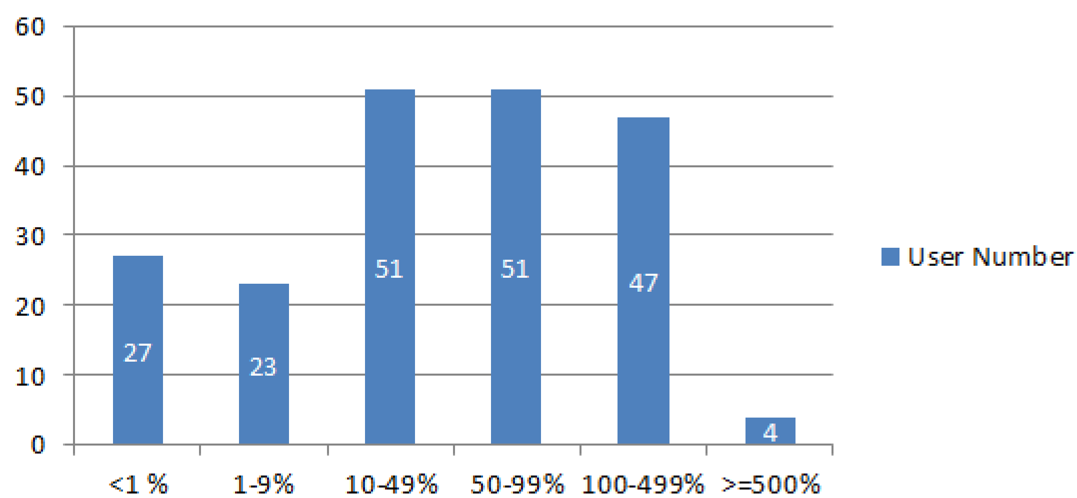


Figure 8-26: Search/Open Document Ratio distribution among engineers population

On an individual user level, as shown in the above table, the use of the search function varies. For example, user3 opened more than 2500 documents without using the search function at all, while user 8 performed more searches and opening documents. Generally speaking, the S/O ratio distributions are relatively evenly distributed across the whole user population. As shown in Figure 8-26, 102 out of 203 users are concentrated in the middle two groups of S/O ratio (10-49% and 50-99%).

S/O Ratio of In-Service Engineers

This study concerned the change of the S/O ratio of the total user group throughout the experimental period. For this user group which contains all In-Service Engineers using Daedalus. It was assumed that if the S/O ratio increased throughout the experiment period, then less repair case document would have been open per search event.

To perform this study, the overall statistics for the search events and document events were needed. Two overall usage indicators were used: the number of search event per 12-week period as shown in Figure 8-23 in subsection 8.7.1, and the number of opened document per 12-week period as shown below.

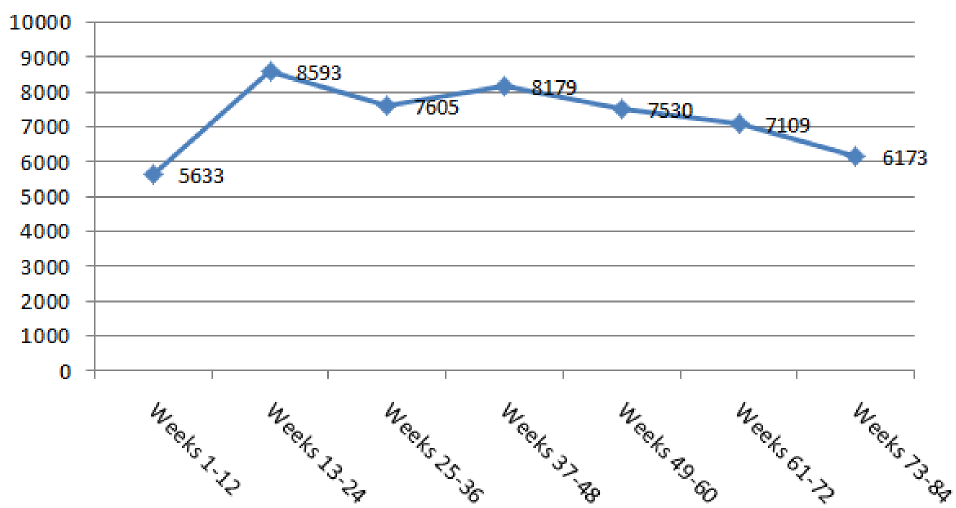


Figure 8-27: Number of opened documents per 12-week period

By dividing the nubmer of search events of each individual 12-week period by the number of opended document in the corresponding period, the S/O raition for each 12-week period during 18 months the were obtained. This is illustrated in Figure 8-28 below:

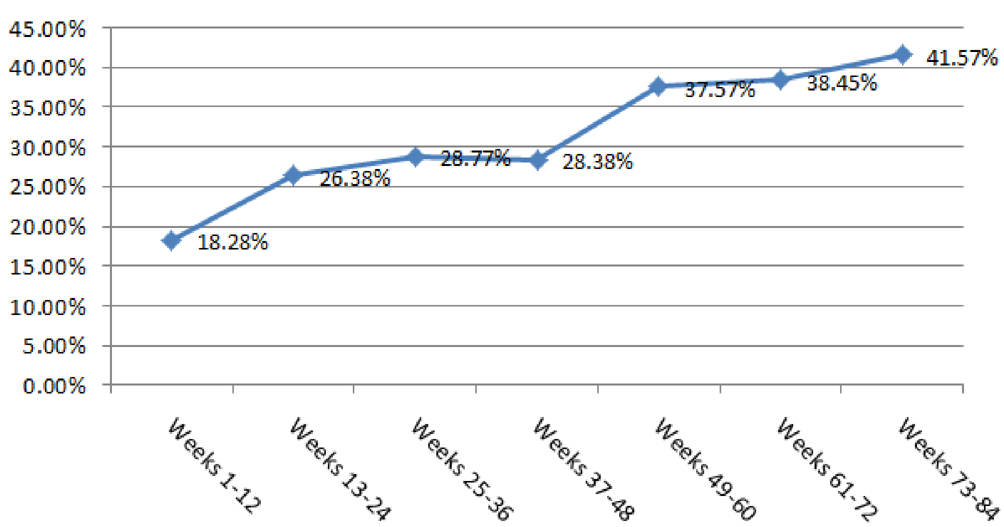


Figure 8-28: In-Service S/O Ratio experiment period

According to this data, the S/O ratio rose from 18.28% during the first 12-week period to 41.57% during the last 12-week period. At 18.28% S/O ratio, 5.47 documents were opened per search on everage. At 41.57%, this indicate 2.4 documents were opened per search. This yeilded the following observation:

Key Observation 19: A significant change was recorde in average search behaviour for the engineers. The number of document open per search by had been reduced by more than half by the end of the experiment period.

8.8 Review of Main Experiment Deliverables

From Sections 8.3 to 8.7, empirical studies and evaluation activities on the experiment data are presented. These were performed to generate the required experiment deliverables which contribute the research objectives.

- In-depth examination of Wing ISS domain semantic context.
- Evaluation of FBCC in term of cost-effectiveness in context capturing.
- Evaluation of Daedalus in terms of adoption level and impact on repair case search activity.

18 key observations have been highlighted during the investigation and analysis in this section. From subsections 8.8.1 to 8.8.3, these key observations are summarised with relation to the three experiment deliverables listed above.

8.8.1 In-Depth Examination of Wing ISS Domain Semantic Context

The purpose of this experiment deliverable was to understand the nature of domain semantic context in Wing ISS. This was done by analysing the search terms used by in-service engineers during the experiment. The related studies are presented in Section 8.3. In the following, the key observations from the study results are outlined, followed by discussion and concluding remarks.

List of Key Observations

Key Observation	Description
Key Observation 1	A small percentage of search terms were associated with much larger percentage of search events.
Key Observation 2	Search terms usage were significant different between different product categories.
Key Observation 3	Large portion of Wing ISS domain concepts were not available in the organisational glossary.

Figure 8-29: Key observations from examination of Wing ISS domain semantic context

Discussion

As highlighted in **key observation 1**, a small percentage of search terms were used in high percentage of search events. This indicates that the concepts related to these search terms were of high relevance to In-Service engineering activities.

It was highlighted in **key observation 2** that the search terms in different product categories were significantly different. This implied that the concepts applicable for each product category were also different. In particular, the concepts applicable for new product, the A380, were significantly different to those of older products. As new products become available, it is clear that the required engineering context evolves significantly from that of the old products. Future research and development of context aware systems must accommodate this.

In **key observation 3**, it was revealed that large portion of the concept captured in the *Context Model* were also not available in the Airbus standard glossary. This provided insight on the difference between domain context and organisation generic context.

Concluding Remarks on Wing ISS Domain Context

Based on the above discussion, for context aware systems to support domain knowledge work in the aerospace, the examination of Wing ISS domain context revealed the following elements that need to be considered:

- Context aware systems shall ideally allow prioritisation of context capturing to target context that is of high relevance to the specific engineering domain.
- Context aware applications need to be flexible to adapt regularly and capture context of evolving engineering designs to suit engineering information needs.
- For context aware systems to be adopted by operational level knowledge workers such as in-service support, the difference between domain context and organisation generic context need to be addressed.

8.8.2 Cost-effectiveness Evaluation of FBCC

The cost-effectiveness of FBCC was evaluated from two perspectives: firstly by analysing the captured context, and secondly by analysing how the captured context was utilised. Studies were carried out to analysed different versions of the *Context Model.* An automatic repair case search simulator was developed to allow search terms expansion to be simulated with different *Context Model* configurations. Additionally, usage data were studied to understand how the search terms suggestion functionality was used. From these studies, it was also possible to understand how the underlying context model evolved during the experiment period.

The related studies are presented in Sections 8.4, 8.5 and 8.6. In the following, the key observations from the study results are outlined, followed by discussion and concluding remarks.

List of Key Observations

Key Observation	Description
Key Observation 4	The *Context Setup* phase made large portion of initial contribution to total amounted of captured context. The accumulation rate of context elements became more gradual during the *Context Feedback* phase.
Key Observation 5	Despite the slower accumulate rate, the total amount of captured context elements during the *Context Feedback* phase was significant.

Key Observation 6	It was evident that for traditional product categories, the majority of top search terms have been captured as at least one type of context elements in the *Context Model*.
Key Observation 7	For new product category A380, the proportion of top search terms captured as *context element* was lower when compared to that of SA and WB & LR.
Key Observation 8	Some top search terms representing key Wing ISS domain concepts were not captured in the *Context Model*.
Key Observation 9	Compare to the eventual benchmark result, significant degree of search terms expansion was in place by the first 20% (18 out of 89 weeks) of the total experiment period timespan.
Key Observation 10	The context captured during the *feedback stage* allowed the search terms expansion functionality to be fine turned gradually throughout the experiment period.
Key Observation 11	The search terms expansion functionality was particular effective for search terms that were frequently used. It was evident that if a given search term was used more; it'd be more likely to be captured in the *Context Model*.
Key Observation 12	Some search terms were captured as effective search terms despite not having been used by the engineers at all.
Key Observation 13	The overall usage level of search suggestion was significant during the experiment period, on average, engineers were more likely to use search suggestions when they appeared.
Key Observation 14	40 of the effective search terms were not clicked on despite being suggested to the engineers.
Key Observation 15	It was evident from this table that search suggestion for longer search terms are more likely to be used by the engineers.

Figure 8-30: Key observations from cost-effectiveness evaluation of FBCC

Discussion

The following discussions is separated into three subsections: context capturing, utilisation of semantic context, and then utilisation of effective search terms

1- Context Capturing

As highlighted in **key observations 4 and 5**, the *Context Setup* phase contributed more context elements in a shorter timespan. The accumulation rate of context elements became more gradual during the *Context Feedback* phase. Despite the slower accumulate rate, the total amount of captured context elements during the *Context Feedback* phase was significant.

The result of the context capturing activity was evaluated by examining how popular search terms in each main product category were captured in *Context Model* as semantic context.

It is highlighted in **key observation 6** that for traditional product categories, the majority of popular search terms had been captured at least as one type of context element in the *Context Model*. Therefore it can be concluded that, for traditional product categories, the feedback based context capturing activity had been effective.

For the new product category A380, the proportion of top search terms captured as context element is lower based on **key observation 7**. This is related to the fact that there are far fewer number of A380 repair cases. A380 has been in-service for far shorter period than aircraft models in SA and WB & LR categories, and therefore accounts for significantly lower levels of in-service repair demand. Additionally, **key observation 8** points to the fact that some top search terms representing key in-service domain concepts were not captured even for traditional product categories.

This point to a need for better analytic support for on-going user-driving context capturing activity, so that the distinct search terms can be made more visible for capturing. Such data could include for example a regular update to top search terms used by engineers. This is further discussed in Section 9.6 where potential future work is discussed.

2-Utilisation of Semantic Context

The utilisation of semantic context was evaluated by simulating repair cases searches using the Daedalus Search Simulator, as discussed in Section 8.5. As highlighted in **key observations 9**, significant degree of search terms expansion was in place by the first 20% (18 out of 89) of the total experiment period time span. This implied that much of the benefit bought by semantic search expansion were realised early on in the experimental period. On the other hand, as highlighted in **key observation 10**, the context captured during the feedback stage allowed the search terms expansion to be fine turned gradually throughout the experiment period.

According to **key observation 11**, the search terms expansion capability was particularly effective for popular search terms. This can be regarded as evidence that that the semantic context was captured in a way that prioritises concepts that were relevant to Wing ISS activities.

3- Utilisation of Effective Search Terms

The utilisation of effective search terms was evaluated by studying how the search terms suggestions were used by the engineers. The overall usage of search terms suggestion was highlighted in **key observation 13** to be of a significant level. On average, the engineers were more likely to use a search terms suggestion than typing in the search term manually. Comparing to search suggestions functionalities that are typically available with commercial information search applications, the search suggestions provided by Daedalus was captured by knowledge workers themselves and was highly relevant to their daily work.

The effective search terms were observed to be used more frequently for longer search terms, as observed in **Key observation 15**. Since complex search terms with multiple concepts tend to be quite long, this is an indication that using effective search terms as search suggestions helped the engineers to identify and focus on useful search terms that will lead to relevant information.

Despite this significant usage level, the study also revealed that some of these effective search terms had actually never been used by the engineers as search terms, as revealed in **key observation 12**. Another 40 effective search terms, as revealed in **key observation 14**, despite used by engineer as search terms, were never chosen when appeared as search suggestions.

Based on this, a potential improvement would be to provide better analytic support such as usage data on the search terms suggestion. This would allow knowledge workers to setup and maintain the list of effective search terms with more accuracy and efficiency.

Concluding Remarks on cost-effectiveness

As analysed above, much of the context was captured and started being utilised within the first 20% of the total timespan of the experiment. The repair case curator only took part in 3 one-hour sessions to perform the initial context capturing, in additional to providing context feedback while working on his day-to-day task. This level of investment in expertise time is quite minimal and acceptable to the business.

For both types of context being captured, the level of utilisation was satisfactory. It was revealed that concepts that were related to frequent search terms were more likely to be captured and utilised via search terms expansion. As for search terms suggestions, there was clear indication that engineers favour the use of search terms suggestions, especially for complex search terms.

Based on the above discussion, the cost-effectiveness of FBCC can be considered as satisfactory – the level investment in expertise is minimal while the context aware functionalities were proved to be effective. The justification of cost-effectiveness is further supported by the impact on the In-Service repair case search activity, this is discussed in subsection 8.8.3.

8.8.3 Evaluation of Daedalus in terms of adoption level and impact on repair case search activity

The usage data of Daedalus was analysed to evaluate Daedalus in terms of adoption level and impact on repair case search activity. This included studying the average usage of basic functionalities such as search and opening documents over the 18 months experimental period. The distribution of the top users was also studied in terms of engineering disciplines and locations.

The related studies have been presented in Sections 8.7 and 8.8. In the following, the key observations from the study results are outlined, followed by discussions and concluding remarks.

List of Key Observations

Key Observation	Description
Key Observation 16	Usage of Daedalus search function had been consistent at a significant level while rising throughout the majority of experiment period.
Key Observation 17	Daedalus was being evenly used between main engineering disciplines in the Wing ISS department.

Key Observation 18	Top users are distributed in the UK and US by proportion with respect to team size.
Key Observation 19	A significant change was observed in average search behaviour for the engineers. The number of document open per search on average had been reduced by more than half by the end of the experiment period.

Table 8-19: Key observations from evaluation of Daedalus

Discussion

The following discussion is separated into two subsections: Adoption of Daedalus as a repair case search tool and its impact on research case search activity.

1- Adoption of Daedalus as a Repair Case Search Tool

It is evident that the search function had been well integrated into the daily repair case search routine. As highlighted in **key observation 16**, the level of search activity had remained consistent at a significant level whilst rising throughout the majority of experimental period.

The level of adoption by the In-Service engineers is highlighted in **key observations 17 and 18**. The number of stress engineer who featured in the top users list of Daedalus is equal to that of design engineers. The number of engineers from Wichita in the top users list, although smaller than that of Filton, reflects the comparative size of the repairs times in these two locations. It is worth pointing out that the Wichita engineers in the USA had never had any direct engagement with the author, and were using Daedalus and without instruction. Despite this, the usage level by engineers in Wichita remained significant as indicated in **key observation 18**.

2- Impact on the Repair Case Search Activity

A key impact on how engineers search and use repair case information has been identified in **key observation 19**. On average, the number of repair cases opened per search had dropped by more than half.

Considering that the overall Wing ISS way of working had no major change throughout the Daedalus experimental period, it can be inferred that the implementation of Daedalus and the application of the FBCC as context capturing approach had been key contributory factors for this important impact. Engineers need to spend a considerable amount of time to perform in-depth inspection of the suitability of a repair case, therefore it can be inferred that reduction in number of repair case being opened per search, because they are more relevant, leads to reduction of time which the engineers need to inspect repair case document unsuitable for task at hand.

Without further study, it is difficult to understand in-detailed how the two functionalities for context utilisation contributed to this impact. However, it can be strongly inferred that the significant coverage of search expansion on top search terms, would allow engineers to retrieve related cases that previously could not be found. Also the fact that long and complex search terms construction are aided by search suggestion capability would also lead to more salient search results.

Additionally, other non-search related activity may have been impacted by the adoption of Daedalus. For example, the ability to see how engineers perform search via the usage data may have allowed the repair case curator to improve metadata quality and consistency of the archiving process, allowing the engineers to access suitable repair cases more efficiently.

Conclusions and implications

Based on these key observations, it can be concluded that Daedalus has been well adopted as a repair case search tools, and had been integrated into the daily In-Service Repair engineering routine for both engineering disciplines and in different Airbus locations.

It was observed that engineers' behaviours in search and opening document had changed significantly over the course of the experiment. At the end of the experiment, on average the number of documents opened per search had dropped by half.

Since engineers need to spend time to evaluate any opened repair case document, change can be regarded as an indication that In-Service engineer were more efficient at search for useful repair cases at the end of the experiment.

Although more in-depth studies would be required to identify impact of specific functionalities of Daedalus, as well as other potential impact on non-search related activity, based on the existing study results, it can be concluded that the introduction of Daedalus had contribute to the department's overall efficiency in providing In-Service repair support.

8.9 Summary

In the experiment phase of this research, an experiment was conducted to capture and utilise context in the Wing ISS department of Airbus. The experiment took place over an 18 months period with Daedalus deployed as a context aware system for repair case search. Daedalus enabled the experiment application of **F**eedback **B**ased **C**ontext **C**apturing (**FBCC**) to capture Wing ISS context while allowing the captured context to be utilised via search terms expansion and search terms suggestion.

The key events of this experiment are outlined in Section 8.1. Two types of experiment data were generated: 10 versions of the *Context Model* and usage data of Daedalus. An overall introduction of these two types of data is given in Section 8.2.

The empirical study and evaluation activities consisted of a series of studies on the above mentioned experiment data. As mentioned in Section 8.2 and reviewed in Section 8.8, the aim of these studies was to generate the following key deliverables:

- In-depth examination of Wing ISS domain semantic context.
- Evaluation of FBCC in term of cost-effectiveness in context capturing.
- Evaluation of Daedalus in terms of adoption level and impact on repair case search activity.

The studies to examine Wing ISS domain semantic context is presented in Section 8.3. The studies for the evaluation of FBCC are presented in Sections 8.4, 8.5 and 8.6. The evaluation of Daedalus is then presented in Section 8.7.

Resulting from these studies, the key natures of what can be thought of as the Wing ISS domain semantic context were identified. This provided insight on aspects which future research and development of context aware systems will need to consider in order to further support knowledge work in the Aerospace sector and in fact in other domains and industries that have similar requirements.

The cost-effectiveness of FBCC was also considered to be satisfactory in this experiment. The time investment from the repair case curator – the domain expert involved in the initial context capturing – was considered to be acceptable throughout the 18 months period. The search terms expansion functionality, which utilised the captured semantic context, was particularly effective for context related to popular search terms. The search terms suggestion functionality, which utilised the captured effective search terms, was used regularly by the engineers especially for long and complex search terms.

It was clear from the evaluation of Daedalus that the adoption of Daedalus as a repair case search tool was very satisfactory. The usage of the search function, for example, was consistently on a significant level which kept rising throughout the majority of the experimental period. The impact of Daedalus on repair case search activity can be observed from the drop in average number of documents open per search. Since engineers need to spend time to evaluate each open repair case document, it was reasonable to deduce that the application of Daedalus had contributed and is continuing to contribute to the overall efficiency and effectiveness of Wing ISS.

9 Conclusions

In this chapter, a conclusive discussion for this research is presented. This starts with a review of the research background and drivers in Section 9.1. The research objectives are then reviewed in Section 9.2 to present how these research objectives have been addressed by the various research activities and research outputs. The key contribution of this research are summarised in Section 9.3, followed by the industrial impact in Section 9.4 and an assessment of the limitations of this research in Section 9.5. Finally, this thesis is finished with a discussion on potential future work in Section 9.6.

9.1 Research Background and Drivers

One of the issues faced by the aerospace industry is that of knowledge loss. This provides some of the impetus for research work in knowledge management and information technology. Among the existing research works, one of the key topics has been that of context aware systems. Context aware systems provide the potential capabilities to capture and utilize contextual information that are relevant to users' information needs, and allow valuable information to be distributed to the right user at the right time (Dey, 2001). These capabilities are perceived to be ideal since context is the most at issues for knowledge of individuals or groups to be understood by another (Alavi & Leidner, 2001).

Various research projects within the aerospace industry have taken place to explore the application of context aware systems. However, there is still much to be learnt about how context aware systems can be developed and applied in daily engineering activity.

Driven by the above factors, the research aim of this project was "to *investigate the application of context aware systems to capture and utilise context to support knowledge work in the aerospace industry"*. During the course of this research, four research objectives were addressed by research activities. These are reviewed in Section 9.2

9.2 Review of Research Objectives

It is useful to provide an overview on how results from research activities contributed to research objectives of this project. Detailed discussions are presented to review research objectives from subsections 9.2.1 to 9.2.4, with an overview presented in Table 9-1 in subsection 9.2.5.

9.2.1 Review of Research Objective 1

Research objective 1 was achieved in the investigation phase *to understand the state of art in research, development and application of context aware systems*. Resulted from the literature review, the classifications of context and context aware techniques reflect how context were defined and dealt within the existing literature. Applications provided by existing context aware systems to support knowledge work were summarised. Additionally, research issues of industrial applications for context aware systems were discussed. The research gaps, resulted from the state of the art review, identified potential areas for research and development from existing context aware systems.

9.2.2 Review of Research Objective 2

Research objective 2 was firstly investigated in the investigation phase *to understand the nature of context with relation to engineering knowledge work in the aerospace industry*. After industrial case studies, the context requirements for an ideal context aware system to support knowledge work were identified. These requirements were related to context related issues that engineers faced while performing industrial practice to capture and reuse engineering experience. These were used as input to review research objectives and identify research direction for the experiment phase.

In the experiment phase, this research objective was further investigated with extended scope to focus on the Wing ISS domain. In particular, the search terms and associated domain concepts used by engineers in their day-to-day repair case search were studied. Search terms used by In-Service engineers were captured amongst other usage data during the experimental period. These search terms shed light how domain concepts were used. An in-depth examination of domain semantic context was performed by conducting a series of studies on the following:

- What search terms were used by in-service engineers and how often they were used?
- The difference of search term usage among different product categories
- The difference between concepts applicable to Wing ISS domain and those included in organisational level glossary.

The findings from these studies provided insight to aspects of domain semantic context which was not identified by previous literature. These aspects shall to be considered in future research and development of context aware systems. This will be further reviewed in Section 9.3.

9.2.3 Review of Research Objective 3

Research objective 3 was achieved in the experiment phase to *investigate a cost-effective approach to capture domain context*. This research objective was achieved by the experimental application of **F**eedback **B**ased **C**ontext **C**apturing (**FBCC**) and the subsequent evaluation activities.

With the FBCC approach, the author proposed to perform context capturing by applying different context capturing techniques in different phases, and increasingly let knowledge workers take the lead in context capturing. This innovative approach was applied during the experimental period to capture semantic context and effective search terms applicable to the Wing ISS, using Daedalus as the enabling platform. This resulted in 10 different versions of *Context Model* retained in different time of the experimental period. It was thus possible to use these versions to fully understand the how context was being captured and utilised during the experiment.

The cost-effectiveness of FBCC was then evaluated by analysing these different versions of *Context Model* and the usage data of Daedalus. This was to understand the following:

- The accumulation rate of context element.
- The association between captured context and top search terms

- The evolvement of context utilisation along the experiment period for each type of captured context.

The findings from these studies provided an indication on what can be thought of as the cost-effectiveness of FBCC. By considering the time spent required from knowledge worker and the level of context utilisation, the author argued that the cost-effectiveness of FBCC had been satisfactory during this experiment. Additionally, it was identified that better analytical support would help to improve the effectiveness of FBCC further.

9.2.4 Review of Research Objective 4

Research objective 4 was added in the experiment phase to *explore the application of context aware systems to support aerospace knowledge work in operational settings*. This research objective was achieved by the development, deployment and evaluation of Daedalus as a context aware system to support repair case search in Wing ISS department during the experiment.

Daedalus provided text-based search functionality for In-Service engineers to search for relevant past repair cases among different product categories. In additional to this search functionality, context capturing and context utilisation functionalities were implemented. The context capturing functionalities were implemented to capture semantic context and effective search terms. The context utilisation functionalities then utilised these two type context to provide search terms expansion and search terms suggestion.

After the experiment period, Daedalus was evaluated in terms of adoption level and its impact on repair case search activities. These were conducted by analysing the usage data to understand the following:

- Evolvement of usage level throughout the experiment period.
- Distribution of top 100 users between engineering disciplines and site locations.
- Change in repair case search behaviour in term of number of documents opened per search.

This was a critical part of the research, Daedalus had been designed as a context enabled in-service support tool AND an investigative tool for this research. Based on the findings from these studies, it can be concluded that Daedalus had been well adopted as a repair case search tool. It was observed that on average the number of documents opened per search had dropped by half amid consistent rising usage level. The author argues that this is a clear indication that the introduction of Daedalus had contribute to the department's overall efficiency in providing In-Service repair support.

9.2.5 Overall View of Research Objectives vs. Contributing Outputs

An overview is provided in Table 9-1 which highlights the connections between research objectives, research activities and research outputs that contributed to the research objectives. Additionally, the chapters in this thesis corresponding to each research activity are also indicated.

Research Objective	Research Methods (Chapter) **- Contributing Outputs**
RO1: **To understand the state of art in research, development and application of context aware systems in academic, public and industrial domains.**	Literature review on related research areas (Chapter 2) - Classification of context - Classification of context aware technique - Applications provided by existing context aware systems - Research issues related to industrial application
	State of the art review on context aware systems (Chapter 3) - Gaps in context aware systems research and development
RO2: **To understand the nature of context with relation to engineering knowledge work in the aerospace industry.**	Case studies of aerospace engineering activities (Chapter 4) - Context requirements for context aware system to support knowledge work
	Experiment to capture and utilise domain context (Chapter 8) - 10 different versions of *Context Model* - Daedalus usage data
	Empirical study and evaluation (Chapter 8) - In-depth examination of Wing ISS domain semantic context
RO3: **To investigate how engineering domain context can be captured in a cost-effective manner.**	Experiment design (Chapter 6) - **F**eedback **B**ased **C**ontext **C**apturing approach (**FBCC**)
	Experiment execution and system deployment (Chapter 8) - 10 different versions of *Context Model* - Daedalus usage data
	Empirical study and evaluation (Chapter 8) - Evaluation of feedback based context capturing
RO4: **To explore the application of context aware systems to support aerospace knowledge work in an operational setting.**	Experiment design (Chapter 6) - Conceptualisation of Daedalus
	System development for Daedalus (Chapter 7) - Implementation of Daedalus
	Experiment to capture and utilised domain context (Chapter 8) - Daedalus usage data
	Empirical study and evaluation (Chapter 8) - Evaluation of adoption level and impact of Daedalus

Table 9-1: Research Objectives vs. Research Activities & Contributing Outputs

9.3 Summary of Key Contributions

Research objectives 2, 3 and 4 were achieved in the experiment phase of this research. Each of these research objectives was based on areas that were under researched among previous research work. These topics include: detailed examination of domain context, cost of domain context capturing, and the demonstration of the benefits of context aware systems in operational setting.

The key research outputs of this project bring contributions to each of these under researched topics. These include the following:

- An In-depth examination of Wing ISS domain semantic context
- The FBCC approach
- Daedalus – the Context Aware System for Repair Case Search

The nature of these contributions is discussed in the following subsections 9.3.1 to 9.3.3.

9.3.1 An In-depth Examination of Wing ISS Domain Semantic Context

The nature of Wing ISS domain semantic context was subjected to in-depth examination during and after the experiment. In particular, studies were conducted to analyse the search terms used during the experiment. This was to understand what search terms and concepts were used in the Wing ISS domain. As mentioned in Section 8.8, the following observations were made:

- A small percentage of search terms were associated with much larger percentage of search events.
- Search terms usage was significantly different when in different product categories.
- A large portion of In-Service Support concepts were not available in the organisational glossary.

There was no previous research in the reviewed literature to systematically study domain semantic context to such a detailed extent. The author argues that this in-depth examination conducted on engineering domain semantic context was the first of its kind.

Before this study, there was no observation on how the specific nature of domain semantic context might influence the requirements of research and development of context aware systems. Each of the above observation can be regarded as a critical contribution to this topic:

- The first observation indicates the need to prioritise context capturing to target context that is of high relevance to the target engineering domain
- The second observation indicates the need for context aware applications to be flexible to adapt regularly and capture context of evolving engineering design to suit engineering information need.
- The third observation indicates that for context aware systems to meet the need of specific domain, the difference between domain context and organisation generic context need to be addressed.

9.3.2 The Feedback Based Context Capturing Approach

The FBCC approach is a context capturing approach that utilises user feedback to improve and validated captured context. It can be regarded as a novel approach to facilitate context capturing in three aspects. These are discussed in detail in the following:

The leading role of knowledge worker in context capturing activities

In 14 months of the 18 months experimental period, the application of FBCC was in the *Context Feedback* phase. Within this phase, the repair case curator took the sole responsibility to improve and validate context captured in the *Context Model*. This level of knowledge worker involvement is unique and novel compared to context capturing approaches reviewed in the literature, both in term of nature of responsibility and also in the length of the process.

The leading role that is assumed by the repair case curator ensured that the context capturing activity remained agile, focussed and quality ensured throughout the experiment. As shown in the evaluation studies presented in Sections 8.4 and 8.5, this on one hand ensured that context elements emerged from the Daedalus usage data were captured, and on the other hand allowed corrective measures to take place if the utilisation of a given captured context element was not ideal. Meanwhile, the length of the application process provided considerable new insight into how the accumulation of captured context evolves during a substantial period of time.

Additionally, this feature of FBCC provides knowledge workers the control over the context capturing activities. This makes it possible for context capturing activity to take place within their day-to-day engineering activity. This ensures that the approach and the system have longevity and the flexibility to develop with new products and their associated features. This is particular relevant as the aerospace sector adapts to the use of composites and more hybrid approaches of aerospace engineering.

Phase-based and hybrid approach to capture context

A combination of context capturing techniques was systematically applied in a phase-based manner within FBCC. During its application in the use case of repair case search, the profiling of Daedalus usage in the *Usage Profile* phase provided the raw information for context capturing activities in the *Context Setup* phase to based on; the *Context Setup* phase allowed the author and repair case curator to setup early versions of context model, these provided a ideal starting point for the repair case curator to lead the context capturing activities during the *Context Feedback* phase.

Among systems that were reviewed in the state of the art review, there were other systems that applied a variety of context capturing techniques at different levels of use and effectiveness. However, the phased based manner in FBCC to systematically applied different techniques, as described above, is a novel aspect compared to related research works.

Cost-effective Context Capturing Approach for Domain Knowledge Work

In the evaluation studies, the cost-effectiveness of FBCC was analysed. The effectiveness of the approach was evaluated from both context capturing and context utilisation perspectives. From a context capturing perspective, it was revealed that the FBCC approach was able to capture concepts that were of high relevance to the Wing ISS Domains. From a context utilisation perspective, a significant degree of search terms expansion was in place by the first 20% (18 out of 89 weeks) of the total experimental period, while the search terms suggestions proved to be frequently used by engineers in particular for long and complex search terms. It can be concluded from these evidences that the FBCC approach allowed Wing ISS domain context to be captured effectively. It is also clear that this approach would work with a variety of large document sets. As seen in Section 4.3, the total storage area of the repair documents was above 60 GB at the time of study.

The cost of applying FBCC was not exactly measured. However, as the costs mainly come from investing the time of domain expert such as the repair case curator to participate in context capturing activities. During the experiment with Wing ISS, the repair case curator only took part in 3 one-hour sessions during the *Context Setup* phase , in additional to providing feedback to the *Context Model* while working on his day-to-day tasks. This level of investment in expertise time is deemed to be more than acceptable to the business.

It is based on the above discussion that the FBCC approach can be considered as a cost-effective context capturing approach for domain knowledge work. Additionally, the evaluation studies that were undertaken are unique both in terms of granularity and amount of data studied.

9.3.3 Daedalus – the Context Aware System for Repair Case Search

Daedalus is the context aware system developed to support repair case search in the Wing ISS department. It provides functionalities to allow the capturing of semantic context and effective search terms in the Wing ISS domain. The captured context was used to facilitate search terms expansion and search terms suggestion to support text-based search on various repair case repositories.

The development and deployment of Daedalus can be regarded as a contribution to future investigation of context aware systems in three perspectives. These are discussed in the following:

Building Context Aware Capabilities with Standard Office Tools

Daedalus was developed entirely using standard office information tool and were integrated with MS Excel. Unlike a lot of existing researches which resulted in stand-alone or web-based prototypes using relatively new software standards, the focus was to construct a context aware system using traditional information toolset that was already in place within the aerospace engineering workspace at the time of the research. This enabled the unique experimental investigation to be achieved.

Additionally, by integrating with such standard office tools, Daedalus allowed capturing and utilisation of context with transparency to knowledge worker. This unique nature of Daedalus enabled knowledge workers to take the initiative to capture contextual information and facilitate effective usage, and allowed advanced information search capabilities such as search terms expansion and search terms suggestion to be realised without heavy investment on computational resource.

This development approach filled an under-researched and under-developed gap in current state of the art – application of context aware system in day-to-day information tools. Given the fact that traditional information tools such as MS Word, Excel and Outlook are fulfilling critical roles in majority of enterprise engineering workspace, the author argues that there is much potential for context aware systems to be developed based on these tool, as well as further investigation on other engineering use cases beyond what was presented in the experiment of this research.

Level of Adoption

As evidenced in the evaluation studies in Section 8.7, the usage of Daedalus as a repair case search tool became standard practice for engineers from both contributing engineering disciplines (design and stress) and from different site locations (Filton, UK and Wichita, USA). The level of search events was consistently on an increasing trend throughout the majority of the experiment period.

Among research output in related subjects, there was of no evidence of other work that achieved similar level of industrial adoption both in and outside the aerospace industry. Therefore from a research perspective, the successful adoption of Daedalus and the empirical study on the usage data had been a first of a kind achievement for applying context aware system to support knowledge works in operational settings.

Demonstration of Benefit to the Business

The evaluation of Daedalus usage revealed changes in repair case search behaviour of in-service engineers throughout the 18 months experiment period. The most distinct observation was that the number of documents opened per search had dropped by more than a half. This indicates that the engineers spent considerable less amount of time to inspect repair case documents before identifying relevant repair case to the task at hand.

Therefore, it can be concluded that the introduction of Daedalus to support In-Service engineering activities had contributed to overall efficiency of the department. This can be regarded as a successful demonstration of benefits of context aware systems in operational settings – an under-researched topic identified during this research.

9.4 Industrial Impact

The industrial impact of this research has so far mainly come from further adoption of Daedalus. After the experiment phase of this research, the usage of Daedalus has been maintained with the existing user base and also expanded to new In-Service teams. These post-experiment usage, maintenance and development of Daedalus can be considered as evidence of continuous industrial impact of this research on the collaborating engineering department as well as wider engineering communities within Airbus. These are discussed in the subsections 9.4.1 to 9.4.3.

9.4.1 On-going Daedalus usage in Wing ISS

The experiment with Wing ISS department finished at September of 2012. At the time of writing this thesis (August 2013), in-service engineers in the Wing ISS department had kept using Daedalus as the repair case search tool, while the repair case curator had kept providing feedback to the *Context Model*. Additionally, the department had recruited a full time software engineer to provide maintenance for Daedalus. This software engineer was also commissioned to implement Daedalus for a different In-Service team as discussed in subsection 9.4.2.

9.4.2 Development of Daedalus for Highlift ISS

Between April 2012 and October 2012, software development activities took place to create a sister version of Daedalus − Daedalus Highlift − for the highlift ISS team in Bremen, Germany. The main use case of the Daedalus Highlift are similar to that of Daedalus in the Wing ISS, therefore all the context capturing and context utilisation functionalities were also implemented in Daedalus Highlift.

9.4.3 On-going plan to extend Daedalus to cover full-airframe ISS

In June 2013, it was agreed that Daedalus was to be rolled out to the full airframe ISS perimeter to support repair case search. In additional Wing and Highlift ISS who had been already using Daedalus, the other ISS departments include those covering the airframe repair for fuselage, empennage, and pylon. At the time of writing this thesis, this development work is in scoping phase, with a potential end users population of about 800. This is can be considered as a significant endorsement for the benefit and impact of the research.

9.5 Limitation to the Research

The first limitation of this research was that only one engineering use case was featured in the experiment. The facts that Daedalus was tailored made for the repair case search activity, and that the experiment lasted for 18 months, determined that it was not feasible to include another engineering use cases given the resource and time available. Within ISS domains, the Highlift ISS teams had successfully adopted Daedalus systems and FBCC approach to capture context. However, the limitation of a single engineering use case means that, despite the high adoption level of Daedalus, it was not possible to perform in-depth examination on the context of other engineering domains, neither was it possible to apply FBCC in other engineering scenarios. Ideally this experiment shall be repeated in multiple domains with other engineering use cases.

The second limitation of this research comes from the choice of technology to implement Daedalus. The XML scheme behind the *Context Model* of Daedalus was too simplistic to represent more complicate nature of semantic relationships such as class-instance or degree of relativeness. This was due to the fact that, at the time of development, there was few reusable API libraries provided support to more complex semantic model and yet at the same time compatible with Visual Basic development environment.

The third limitation of this research originated from the manual context capturing approach provided by FBCC. This approach provided openness and transparency to engineer users who were not IT-specialist. However, the limitation of a pure manual approach was revealed during the evaluation on the context capturing activity. In particular, as discussed in Chapter 8, for new aircraft model such as A380, significant amount of top search terms were not captured as semantic context.

Each of the three limitations listed above points to specific aspects that were not fully addressed during this project. In the other hand, these limitations points to promising future aspect for research and development work, these are discussed in details in Section 9.6.

9.6 Future Work

An experiment to capture and utilise context of aerospace engineering activity has been presented in this thesis. This experiment consisted of the repair case search use case from ISS, FBCC as the context capturing approach, and Daedalus as the context aware systems to capture and utilise context to support repair case search activity. Comprehensive empirical study and evaluation has been presented to examine ISS domain context, the cost-effectiveness evaluation of FBCC and the evaluation of Daedalus in term of adoption level and impact on repair case search activity.

In the following, from subsections 9.6.1 to 9.6.3 potential future research and development works that could be based on this research are presented. Some of these potential future works are considered to be desirable to be included in this research should time and resource allowed, while others are deemed to be out of scope of this research, but should now be regarded in the light of what has been achieved in this research.

9.6.1 Conducting similar experiment in other aerospace domains

As discussed in Section 9.5, the main limitation of this research came from the fact that only one engineering use case was featured in the experiment. For this reason, conducting similar experiment in other aerospace domains would be an ideal addition to what has been achieved in this project.

The nature of the engineering use case in the experiment was that of ISS which mainly features engineering works in later stages of product lifecycle. Ideally, it would be desirable to also apply FBCC in engineering works that are related to earlier stages of such project lifecycle such as R&T, feasibility study or early design.

Engineering activities in these earlier stages of product lifecycle are often considered to be more fluid and less repetitive than the repair case search activity. For this reason, which engineering activity to consider as a new use case, how to apply FBCC to such activity, and how the enable the utilisation of captured context might require significant investigation effort. However, the potential benefit of such investigation would complement the contribution of this research, particularly in terms of covering how to capture and utilise context of knowledge work from different stages of the product lifecycle.

9.6.2 Application of more sophisticate context modelling standard

As discussed Section 9.5, the FBCC approach and the context capturing capabilities of Daedalus could be further improved with even more sophisticated context modelling techniques. At the time of development, there were few reusable API libraries that support context modelling standard such as RDF or OWL. It was also deemed out of the scope of this project to devote significant effort to developed API libraries to support the construction of the *Context Model* of Daedalus.

However, for future work, additional development effort to extend the existing Daedalus system to able to work with such context modelling standards should be considered. Such work would enable Daedalus to capture other types of context that might be required for work in other engineering domain, supporting the future work proposed in subsection 9.6.1.

Additionally, application of such modelling standards would also enhance the interoperability between Daedalus and other context aware systems that apply similar standards such as the enterprise search engine Vivisimo Velocity which was being deployed within Airbus (IBM, 2013).

9.6.3 Applying data mining techniques to extract information from usage data

From the empirical study and evaluation activities, it was revealed that better analytical support to gain useful information from the usage data of Daedalus would be promising future work. During the experiment, the repair case curator studied the usage data manually to identify and capture semantic context and effective search terms. Although the context capturing of FBCC was deemed effective, some top search terms were not captured as semantic context, while significant amount of effective search terms were not used by the engineers as search terms suggestion.

For this reason, it would be beneficial to automatically provide analytical information from the usage data to support knowledge workers who perform context capturing activities in the *Context Feedback* phase of FBCC. Such analytical support could be useful for identification of top search terms and tracking of usage level of search suggestion. Additionally, it could also be used to provide more up-to-date information in terms of how a given type of captured context is being utilised in other potential engineering use case. This would be much beneficial for further application of FBCC, as proposed in subsection 9.6.1.

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Appendix A - List of Systems in the State of the Art Review

A-1 System Applying Data Mining Techniques

Table A-1 provides an overview on systems featured in the state of the art review that applied data mining techniques, with the following specific interpretation:

- *Automation Level*: “semi-automatic” system are those with “✓” in both “automatic capturing” and “manual capturing” columns.
- *System Application*: the application type “descriptive information generation” is presented by the acronym “DIG”.

	Automation Level		Specific Data Mining Techniques					System Origin					System Applications
								Research			Commercial		
Reviewed Systems	**Automatic Capturing**	**Manual Capturing**	**Text Analysis**	**Link Analysis**	**Information Clustering**	**Information Classification**	**Pattern Analysis**	**Academic**	**Commercial Research**	**Aerospace Research**	**Public Domain Usage**	**Aerospace Usage**	
CiteSeer (Bollacker, et al., 1998)	✓			✓	✓	✓	✓				✓		Search
Google PageRank (Page, et al., 1999)	✓			✓							✓		Search
Medical Semantic Lexicon	✓		✓					✓					Semantic Lexicon
Watson (Budzik, Hammond, 2000)	✓		✓		✓						✓		Push
Lixto (Baumgarter, et al., 2001)	✓	✓	✓				✓				✓		DIG
Webtop (Wolber, et al., 2002)	✓		✓	✓				✓					DIG Push
Melita (Ciravegna, et al., 2002)	✓	✓	✓					✓					DIG
TAP (Guha, et al., 2003)	✓						✓		✓				Search
ARCH (Sieg, et al., 2003)	✓	✓	✓					✓					Search
Way Point (McMahon, 2004)	✓	✓	✓			✓				✓			DIG Search
KnowItAll (Etzioni, et al., 2004)	✓		✓				✓	✓					DIG Search
Text2Onto(Cimiano, et al., 2005)	✓	✓					✓	✓					DIG
CAFETIERE (Black, 2005)	✓				✓			✓					DIG
VMSP (Ishino, Jin 2006)	✓				✓		✓	✓					Other

SemSearch (Lei et al., 2006)		✓		✓	✓			✓					Search
CIFLEX (Campbell, 2006)	✓	✓		✓						✓			Push
Falcon-S (Wu et al., 2006)		✓	✓					✓					Search
Lockheed Martin DAML-S Architecture (Kogut, 2003)	✓						✓			✓			Other
Context Based Search Platform-Vivace (Redon, et al., 2006)	✓	✓	✓		✓					✓			DIG Search
Leila (Suchanek, 2006)	✓	✓	✓		✓		✓	✓					DIG
TextRunner (Yates, 2007)	✓		✓			✓		✓					DIG Search
User profiling with hierachical context - an e-Retailer study (Palmisano, et al. 2007)	✓					✓		✓					Other
In-Service Cases Search - CASKM (2007)	✓		✓		✓					✓			Push
Dbpedia (Auer, et al., 2007)	✓		✓				✓				✓		Authoring Search
AutoSummary - MS Word	✓		✓									✓	DIG
WebTables (Cafarella, et al., 2008)	✓		✓			✓	✓		✓				Search
reCAPTCHA(Von Ahn, et al., 2008)	✓	✓	✓								✓		Other
Freebase (Bollacker, et al., 2008)		✓	✓								✓		Authoring, DIG Search
LinkedIn	✓	✓		✓							✓		Search Push
K-Search (Dadzie, 2009)	✓	✓	✓				✓			✓			DIG Search
Renlifang/statSnowball (Zhu, et al., 2009)	✓		✓		✓		✓		✓				Search
ReadTheWeb (Mitchell, et al., 2009)	✓		✓		✓	✓		✓					DIG
DGE (Doan, et al., 2009)	✓	✓	✓				✓	✓					DIG Search
Wordle (Viegas, et al., 2009)	✓		✓								✓		DIG
MonoTran (Bederson, et al., 2010)		✓	✓					✓					Other
STAT - Boeing & NASA (Malin, 2010)	✓						✓			✓			DIG Search
Intellexer Summariser	✓		✓			✓	✓				✓		DIG
Copernic Summariser (2010)	✓		✓								✓		DIG

Blekko		✓	✓	✓							✓		DIG Search
BabelNet (Navigli, et al., 2010)	✓		✓	✓		✓		✓					Semantic Lexicon Search
Google Search (2011)	✓	✓	✓	✓							✓		Search Push
MS Bing (2011)	✓		✓	✓							✓		Search Push

Table A-1: Systems applying data mining techniques

A-2 System Applying Semantic Techniques

Table A-2 provides an overview on systems featured in the state of the art review that applied semantic techniques, with the following specific interpretation:

- *Automation Level*: "semi-automatic" system are those with "✓" in both "automatic capturing" and "manual capturing" columns.
- *System Application*: the application type "descriptive information generation" is presented by the acronym "DIG"

	Automation Level		Specific Semantic Techniques				System Origin: Research			System Origin: Commercial		System Applications
Reviewed Systems	Automatic Capturing	Manual Capturing	Ontology Modelling	Resource Description	Simplistic Semantic Representation	Context Inference	Academic	Commercial Research	Aerospace Research	Public Domain Usage	Aerospace Usage	
Amaya (Quint, et al., 1998)		✓		✓				✓				Authoring DIG
Medical Semantic Lexicon (Johnson, 1999)	✓						✓					Semantic Lexicon
Lixto (Baumgarter, et al., 2001) (Commercial 2007)	✓	✓		✓						✓		DIG
Melita (Ciravegna, et al., 2002)	✓	✓	✓				✓					DIG
OntoLogging (Maedche et al., 2002)		✓	✓			✓			✓			DIG Search
CoBra (Chen, et al., 2003)	✓	✓	✓			✓	✓					Push
Hydrogen (Hofer, et al., 2003)	✓			✓			✓					Push Other
TAP (Guha et al., 2003)	✓			✓				✓				Search
Mangrove (McDowell, et al., 2003)		✓		✓			✓					DIG
Vannotea (Schroeter, et al., 2003)		✓			✓		✓					DIG
ARCH (Sieg, et al., 2003)	✓	✓			✓		✓					Search
mSpace (Schraefel et al., 2003)		✓	✓							✓		Search
Context-aware Communication (Henricksen, et al., 2004)	✓		✓			✓	✓					Push

Corese (Corby, 2004)	✓		✓	✓		✓		✓				Search
Knowledge Sifter(Kerschberg, et al., 2004)	✓	✓	✓	✓			✓					Search
OOF (Collier, 2004)		✓		✓			✓					DIG
Text2Onto(Cimiano, et al., 2005)	✓	✓	✓				✓					DIG
CAFETIERE (Black, 2005)	✓				✓		✓					DIG
SUiS (Nilsson, et al., 2005)		✓	✓				✓					Search Other
SPIRIT (Fu, et al., 2005)	✓	✓	✓			✓	✓					Search
SemSearch (Lei et al., 2006)		✓	✓				✓					Search
Falcon-S (Wu et al., 2006)		✓		✓			✓					Search
IkeWiki (Schaffert, et al., 2006)	✓	✓		✓		✓		✓				Authoring DIG
OpenCyc (Matuszek, 2006)		✓		✓						✓		Semantic Lexicon
Lockheed Martin DAML-S Architecture (Kogut, 2003) (AeroDAML)	✓		✓	✓		✓			✓			Other
Context Based Search Platform-Vivace (Redon, et al., 2006) (Gulmini, 2007)	✓	✓			✓				✓			DIG Search
Leila (Suchanek, 2006)	✓	✓	✓				✓					DIG
SemKey (Marchetti, et al., 2007)	✓	✓		✓			✓					DIG Search
WordNet (Miller, et al., 1995)		✓			✓		✓					Semantic Lexicon Search
Dbpedia (Auer, et al., 2007)	✓			✓						✓		Authoring, Search
Freebase (Bollacker, et al., 2008)		✓		✓						✓		Authoring DIG Search
K-Search (Dadzie, 2009)	✓	✓	✓	✓					✓			DIG Search
ReadTheWeb (Mitchell, et al.., 2009)	✓		✓			✓	✓					DIG
MS Live Pivot		✓			✓			✓				DIG
STAT - Boeing & NASA (Malin, 2010)	✓				✓				✓			DIG Search
Amazon	✓	✓			✓					✓		DIG Search Push
BabelNet (Navigli, et al., 2010)	✓		✓				✓					Semantic Lexicon Search
Dictionary.Com - Visual Thesaurus	✓	✓		✓	✓	✓				✓		Semantic Lexicon Search

Google Search	✓	✓		✓	✓					✓		Search Push
MS Bing	✓					✓				✓		Search Push
Knowledge-Based Cost modelling of Composite Wing Structure (Verhagen, etal., 2012)		✓			✓				✓			Search

Table A-2: Systems applying semantic techniques

A-3 System Applying Profiling Techniques

Table A-3 provides an overview on systems featured in the state of the art review that applied data mining techniques, with the following specific interpretation:

- *Automation Level*: “semi-automatic” system are those with “✓” in both “automatic capturing” and “manual capturing” columns.
- *System Application*: the application type “descriptive information generation” is presented by the acronym “DIG”

	Automation Level		Specific Profiling Technique				System Origin					System Applications
							Research			Commercial		
Reviewed Systems	Automatic Capturing	Manual Capturing	Activity Profiling	Physical Sensing	Interests Profiling	Knowledge, Background and Skill Profiling	Academic	Commercial Research	Aerospace Research	Public Domain Usage	Aerospace Usage	
Disseminating Active Map Information to Mobile Hosts (Schilit, Theimer, 1994)	✓		✓		✓			✓				Push
The Context Toolkit (Dey, Abowd, et al., 2000)	✓			✓			✓					Push
Rememberance Agent (Rhodes, Maes, 2000)	✓		✓				✓					Push
Watson (Budzik, Hammond, 2000)	✓		✓		✓					✓		Push
OntoLogging (Maedche et al., 2002)		✓	✓						✓			DIG Search
M-Studio (Pan, et al., 2002)		✓	✓	✓			✓					Authoring
CoBra (Chen, et al., 2003)	✓	✓		✓			✓					Push
Hydrogen (Hofer, et al., 2003)	✓			✓			✓					Push Other
Context-aware Communication (Henricksen, et al., 2004)	✓			✓			✓					Push
Corese (Corby, 2004)	✓		✓					✓				Search
Text2Onto(Cimiano, et al., 2005)	✓	✓	✓				✓					DIG
SUiS (Nilsson, et al., 2005)		✓					✓					Search Other
SPIRIT (Fu, et al., 2005)	✓	✓	✓				✓					Search
ConnectBeam		✓			✓					✓		DIG Search
VMSP (Ishino, Jin 2006)	✓		✓		✓		✓					Other
CIFLEX (Campbell, 2006)	✓	✓	✓		✓				✓			Push

Dogear(Millen, et al., 2006)	✓	✓	✓		✓			✓				DIG Search
Context Based Search Platform- Vivace (Redon, et al., 2006)	✓	✓			✓				✓			DIG Search
User profiling with hierachical context - an e-Retailer study (Palmisano, et al. 2007)	✓		✓		✓		✓					Other
In-Service Cases Search - CASKM (2007)	✓		✓						✓			Push
Office Assistant - MS Office 2000	✓		✓							✓		Push
SeeTrieve (Gyllstrom, Soules, 2008)	✓		✓					✓				DIG Search
LinkedIn	✓	✓			✓	✓				✓		Search Push
Amazon	✓	✓	✓		✓					✓		DIG Search Push
Aloqa (Ternier, 2010)	✓			✓		✓				✓		Search Push
Google Search	✓	✓	✓	✓						✓		Search Push
MS Bing	✓		✓							✓		Search Push

Table A-3: Systems applying profiling techniques

Appendix B - In-Service Support Placement Report

In-Service Support Placement Report

Yifan Xie

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1 Introduction

The Virtual Engineer Demonstrator (VED) project is an EADS enterprise-wide research project aims to improve efficiency of knowledge workers. As part of this project, Knowledge Management of Airbus UK purposed the use case of automatic information push for the engineering process of Wing In-Service Support (ISS).

The Wing In-Service Support department is responsible for providing aircraft wing repair service for damages that fall outside standard repair manual. Its engineers work on a 24 hours a day, 365 days a year based to design and validate repairs requested by airline customer. Their repair tasks are typically with limited time frame, and with relevant data scatter around various data sources. Therefore their engineering process is considered to be an ideal candidate that would benefit from effective automatic information push service.

In order to better understand engineers' information requirement and their working scenario, the author has completed a three months placement with In-Service Support. Working closely with engineers, the author provides suggestion on IT related issue and in exchange obtain first hand engineering process knowledge. This document provides a summary of main activities undertook and achievements.

2 Activity and Achievement

2.1 Observation and suggestion on IT storage process

One observation make by the author is that previously most repair dossiers, called ATA file, are scanned as image-based PDF file. As a result, the file is not text recognizable and doesn't support any text-based search. This is obviously disadvantageous for the engineers i.e. have to look through each file manually for any particular phase. The reason of scanning files as images is largely historical and not relevant any more. On the other hand, engineers are still with the habit of reading paper-based material – They would print the ATA files every time they need one. The author believes that the lack of text-searching ability of existing PDF files helps to consolidate such a habit.

Another disadvantage of imaged base PDF file is that it is roughly double in size compare to the text-base equivalence. This greatly contributes to ISS' problem in storage shortage – their share drive is running out of space.

The author made the suggestion of converting existing ATA files into text-based format to enhance file usability and reduce storage requirements. It is has been adapted by the department, and patch OCR conversion via Adobe Professional trial version has taken places for a large number of ATA files. However, for operational reason, Airbus use Standard Adobe version, which doesn't support batch OCR conversion. This exercise can only continue if the Adobe version is to be upgraded to Professional version.

2.2 Work on Excel database

ISS engineers use several Excel databases to aid the search for past cases similar to their current tasks. During placement, the author helped to improve these databases by writing VBA functions. As a result, engineers now have better access to following past case information:

- **RAS (Repair Approval Sheet):** Marco created in past cases database.
- **ATA file:** Marco is created in past cases database.
- **Off site access:** Past cases database has been improved so that it can be use away from Airbus' setting. Engineers can now access key past case information from home if needed.
- **Static Data:** Marco created in Wide Body and Long Range static database for stress engineer to access past case static data.
- **A380 Database:** New repair case data base is set up for A380

2.3 Understanding engineering process

The author gained understanding of engineering process by the following means:

- Conducting regular interview with ISS manager, design engineers and stress engineers.
- Working on Excel past cases database.
- Familiarizing information tools used by ISS engineers, in particular SAP RMT and AirDoc.

2.3.1 Mapping engineer's information needs

In an effort to capture ISS engineers' information need, information maps are created for both design and stress engineers to identify information of interest and corresponding sources. As shown in the following:

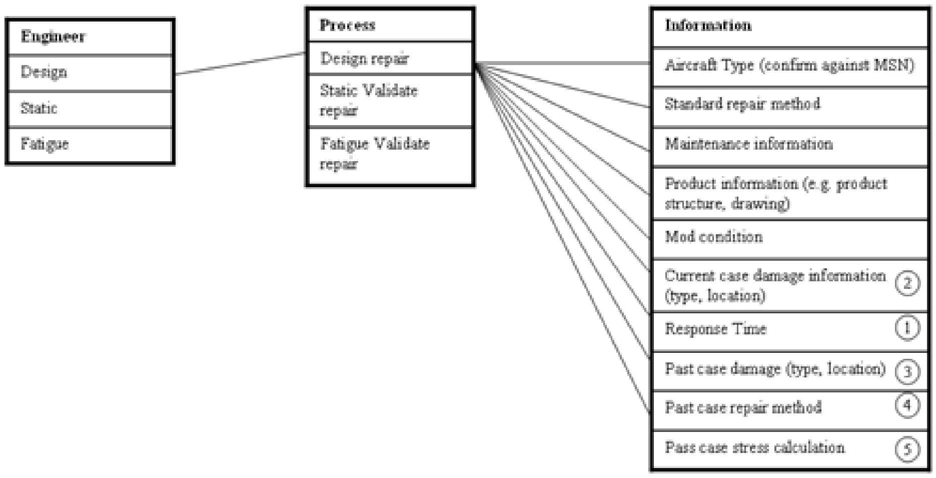

Figure 1: Design Engineer Information Map 1

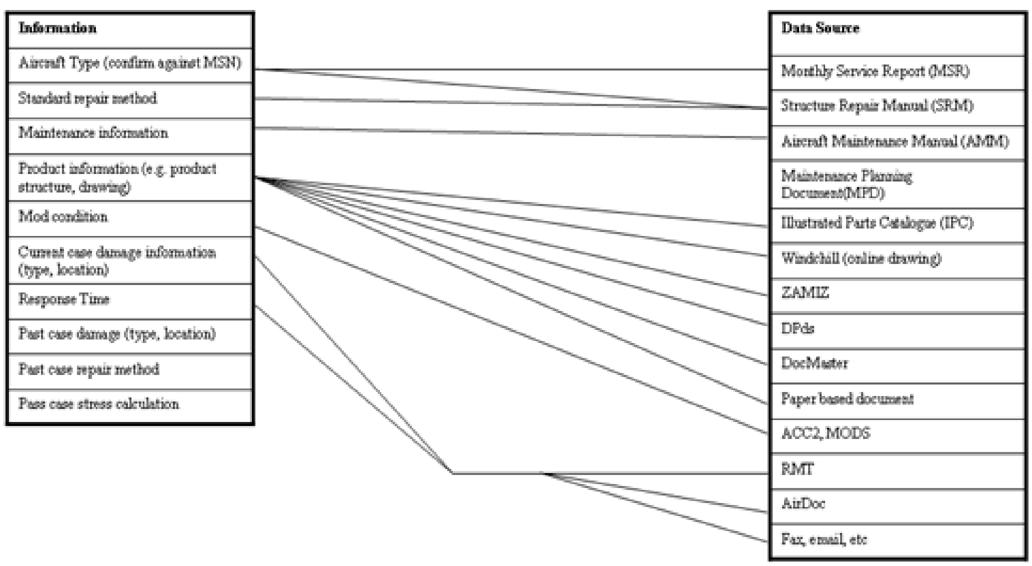

Figure 2: Design Engineer Information Map 2

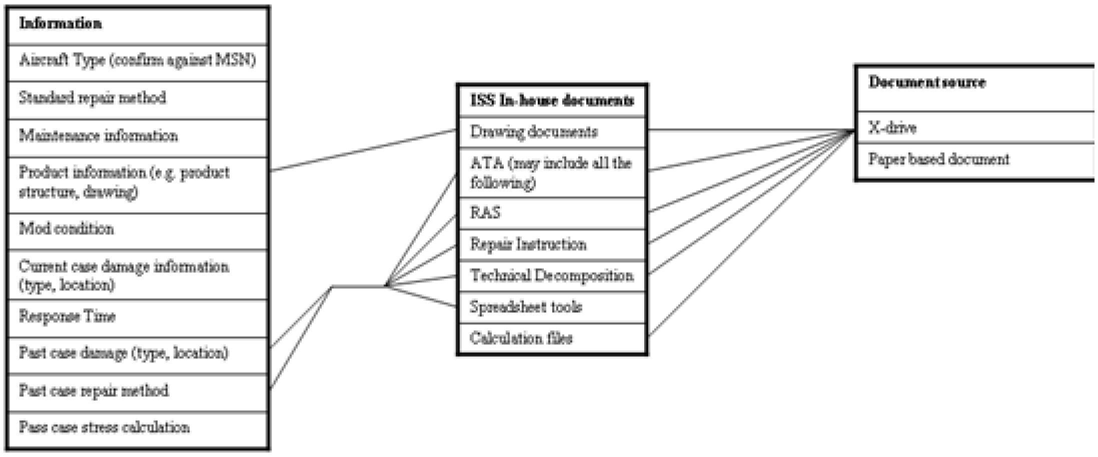

Figure 3: Design Engineer Information Map 3

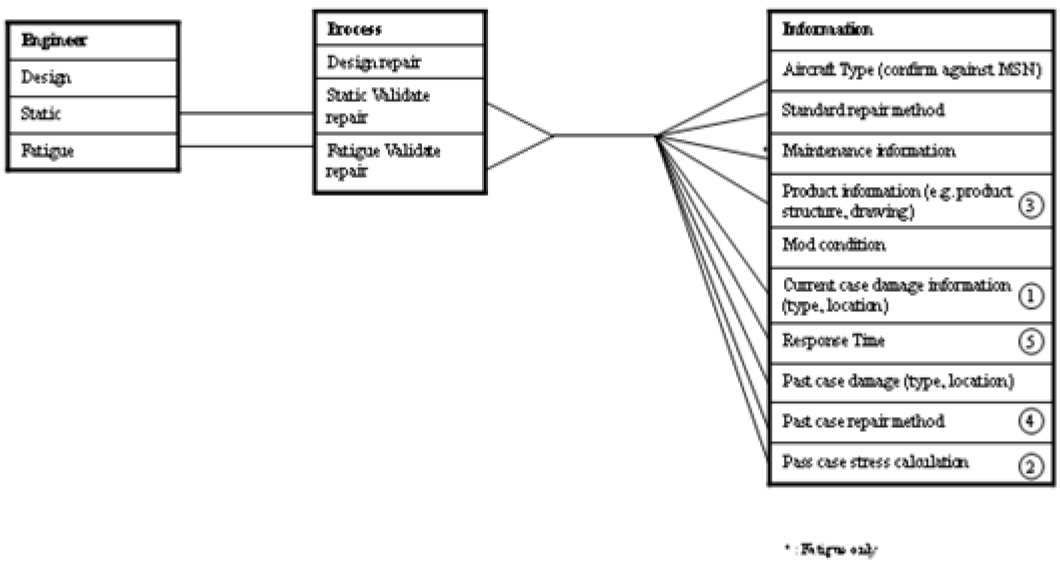

Figure 4: Stress Engineer Information Map 1

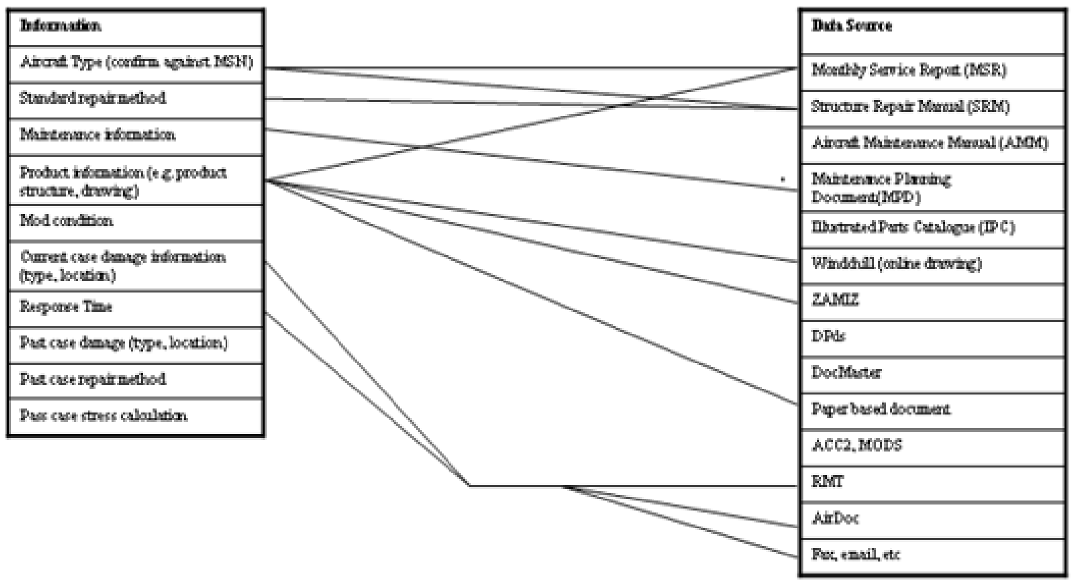

Figure 5: Stress Engineer Information Map 2

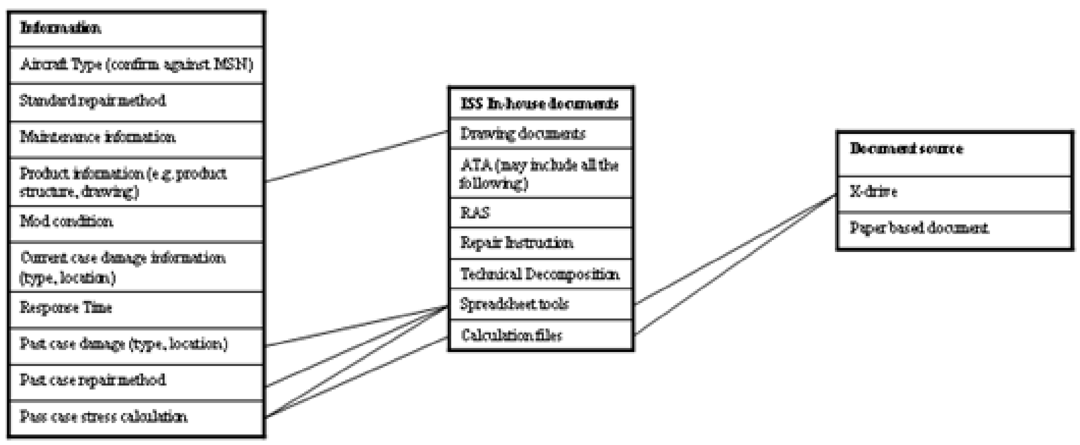

Figure 6: Stress Engineer Information Map 3

As shown in figures 1-6, different information needs and its priority (as indicated by number) are revealed for different types of engineers.

2.3.2 Capturing engineering process

As a result of the placement, the author obtained first hand knowledge of engineering process for In-Service Support. Consequently, an ISS engineering flow chart is produced, detailing different actors and action sequence in a typical case of handling repair request, as shown in figure 7

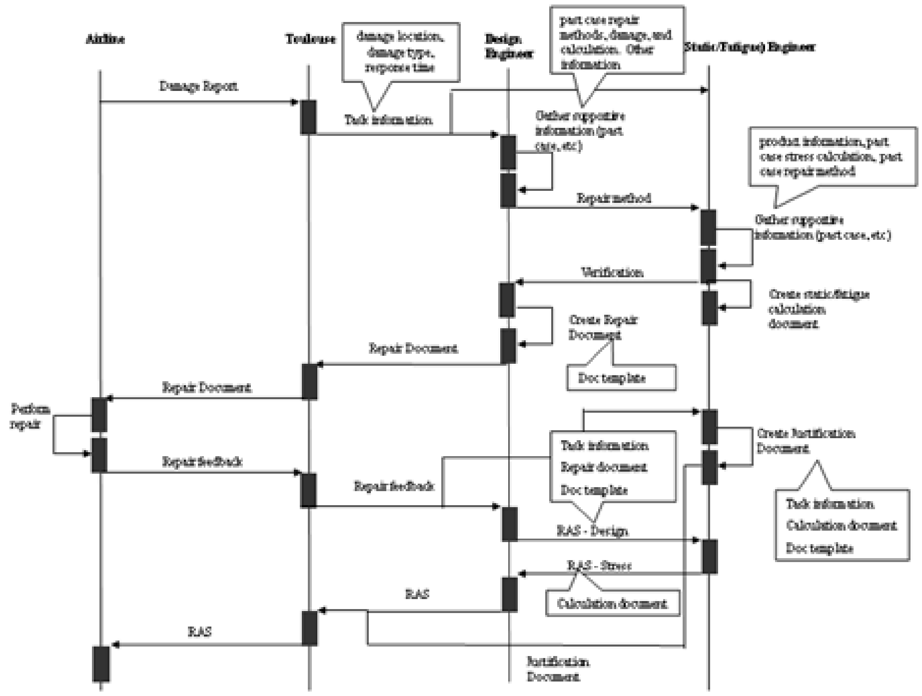

Figure 7: ISS engineering flow chart

2.3.3 Information push software prototype

Findings in this placement are feed back to research activities of the VED project and the author's EngD. To demonstrate how information push service might benefit ISS engineering activities, a software prototype is created.

The software prototype is based on the scenario of:

1. A repair requested being issued by the airline.
2. Toulouse head office forward the request to ISS in the UK
3. Design engineers and stress engineers collaborate to design and validate the repair method, and generate repair documents in the form of technical disposition.
4. Airline performs the repair and feedbacks to Toulouse.
5. Toulouse forwards the feedback to ISS UK in order to issue the Repair Approval Sheet (RAS).

With the focus on a design engineers' perspective, this prototype allows a potential user to select a repair case, design repair methods, create repair document and create RAS. In each stage of the routine, the application would identify the user's need in that particular stage, taking user's profile into account, and push relevant information to the user. The following screenshot in figure 8 shows information of a relevant past case being pushed.

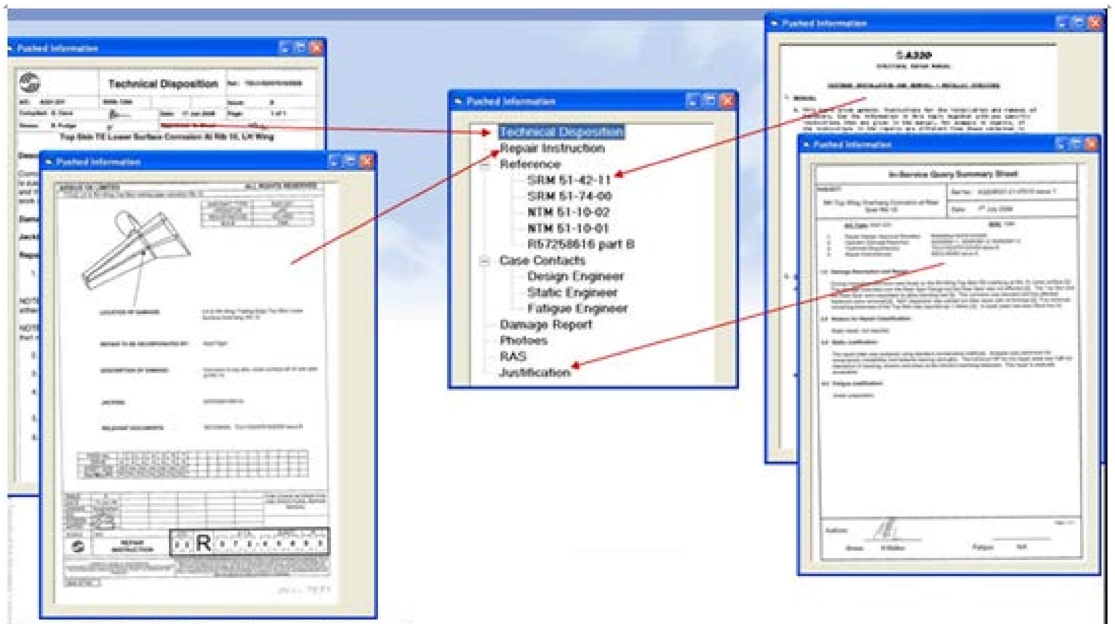

Figure 8: Push of past case information

Appendix C - Detailed Industrial Case Study Data

C-1 Wing In-Service Support Information Systems

Information Repository	Repository type	Description
Monthly Service Report	Company wide online portal	Monthly report about in-service aircraft
Technical Data Centre (SRM, AMM, MPD, etc)	Company wide online portal	Online data source containing official aircraft in-service and maintenance information.
Doc Master	Company wide online portal	Online data source containing internal official procedural documents
Illustrated Parts Catalogue	Enterprise Database Require separate access credentials	Enterprise database that contain key information about aircraft parts
Prime (Windchill)	Enterprise Database Require separate access credentials	Enterprise database for management of product data created for aircraft detail parts.
Zamiz	Enterprise Database Require separate access credentials	Enterprise database for archiving and distribution of technical documents
DPds	Enterprise Database Require separate access credentials	Enterprise database for maintaining product change, drawing schedules and associated release document
ACC2,	Enterprise Database Require separate access credentials	Legacy enterprise database for configuration management for old aircraft models
MODs	Enterprise Database Require separate access credentials	Enterprise database to manage modification to in-service aircraft models
RMT	Enterprise Database Require separate access credentials	Enterprise database for repair inquiry workflow control.
AirDoc	Enterprise Database Require separate access credentials	Enterprise database for generation of repair document template.
Drawing documents	Folder/File system	Production drawings that are proved to be useful, and are specially kept in share drive location.
Repair File Pack	Folder/File system	File pack contain detailed information for each previous repair case, excluding RAS and stress calculation
Repair case spreadsheet	Folder/File system	In-house spreadsheet tools with key meta data extracted for previous repair cases and marco for quick access.
Stress Calculation files	Folder/File system	Collection of folders for stress calculation, with each folder containing stress calculation for specific previous repair case.
Stress files spreadsheet	Folder/File system	In-house spreadsheet tools collaboratively curated to provide key

		information on previous repair cases containing stress work. Used by stress engineers as hint to navigate the share folder for stress calculation files.
RAS Files	Folder/File system	RAS files created for previous repair cases, collected and categorized by individual aircraft.
Pre-defined Solution	Folder/File system	Repair instruction or technical disposition that are created to provide pre-defined solution to well, high occurring understood damage.

Table C-1: Information systems used by Wing In-Service Support

C-2 Wing In-Service Support Interview Data

In the following, interview data resulted from the interview activities with Wing In-Service Support is presented. These interviews were intended to identify key context related issues that engineers face while search and using for repair case documents to handle ISQ tasks.

Firstly, the profiles of the interviewees are presented in C-2.1; secondly, the list of questions used to facilitated semi-structure interview is presented in C-2.2; finally, the summarised results of these interviews are presented in C-2.3.

C-2.1 Interviewee Profiles

In total, 9 employee from the Wing In-Service Support department were interviewed, the interviewees' profiles can be seen in Table C-2

Interviewee 1	
Engineering Discipline:	Design
Experience:	15 years
Key Tasks:	Chief design, giving instruction and directions about repair design.
Interviewee 2	
Engineering Discipline:	Repair case curator, Design
Experience:	17 years
Key Tasks	Managing ISS past case knowledge archive.
Interviewee 3	
Engineering Discipline:	Design
Experience:	8 years
Key Tasks:	Design team leader, managing and allocating ISQ to design engineers.
Interviewee 4	
Engineering Discipline:	Design
Experience:	18 years
Key Tasks:	Design engineer working on ISQ for single aisle aircraft
Interviewee 5	
Engineering Discipline:	Design
Experience:	1 year
Key Tasks:	Design engineer working on ISQ for single aisle aircraft
Interviewee 6	
Engineering Discipline:	Stress
Experience:	20 years
Key Tasks:	Stress team leader, managing and allocating ISQ to stress engineers
Interviewee 7	
Engineering Discipline:	Stress
Experience:	5 years
Key Tasks:	Stress engineer working on ISQ for long range and wide body aircraft
Interviewee 8	
Engineering Discipline:	Stress
Experience:	8 years
Key Tasks:	Stress engineer working on standard repair methods
Interviewee 9	
Engineering Discipline:	Stress

Experience:	3 years
Key Tasks:	Stress engineer specialised in fatigue and damage tolerance calculation

Table C-2: Profiles of Wing In-Service interviewees

C-2.2 Interviewing Questions list

The following list of interview questions were used to facilitated semi-structure interview with the Wing In-Service Support interviews. The interviews were held in the engineers' desk in their normal working setting. Each interview section started with introductory conversation to understand engineers personal profile, as shown in C-2.1. This is then followed by conversation facilitated by the following 15 questions and lasted between 30 - 60 minutes.

1. Looking back, what is the key learning challenge you faced? (Top 3)
2. What is the key knowledge you learnt from the repair case documents for past cases? (Top 3)
3. What is the key information that you are looking for when you are searching for a similar repair case to your current repair job? (Top 5)
4. What does the terms "contextual information" or "context" mean to you?
5. What is the key "contextual information" for you when dealing with ISQ task? (Top 5)
6. What are the most useful functionalities of the repair case spreadsheet for you? (Top 3) and why?
7. What information is missing from this spreadsheet? (Top 3)
8. What information is missing from the repair case documents (Top 5)
9. What functionalities are missing in this spreadsheet? (Top 3)
10. Any suggestions for improvement for this spreadsheet? (Top 3)

C-2.3 Interview Data Analysis for Context Related Issues

In Table C-3 below, data analysis results of the interviewing session is presented. A list of 7 context related issues were mentioned by the interviewees. In this table, the "✓" indicating an issue was mentioned by the corresponding interviewee. The "score" column provided the number of interviewees who mention a particular issue.

	Interviewee 1	Interviewee 2	Interviewee 3	Interviewee 4	Interviewee 5	Interviewee 6	Interviewee 7	Interviewee 8	Interviewee 9	Score
Support of domain semantics	✓	✓		✓	✓	✓	✓		✓	7
Repair case document usage	✓	✓		✓	✓	✓	✓		✓	7
Connection between related information	✓	✓	✓	✓	✓	✓		✓		7
Taking historical context into account	✓		✓				✓	✓	✓	5
Information summary	✓		✓			✓		✓		4
Collaboration support				✓	✓				✓	3
View progress of on-going cases	✓	✓								2

Table C-3: Context related issues as mentioned by interviewees

C-3 Lessons-leant Case Study Data

C-3.1 Mind map for 1st workshop with Fuel System Knowledge Management

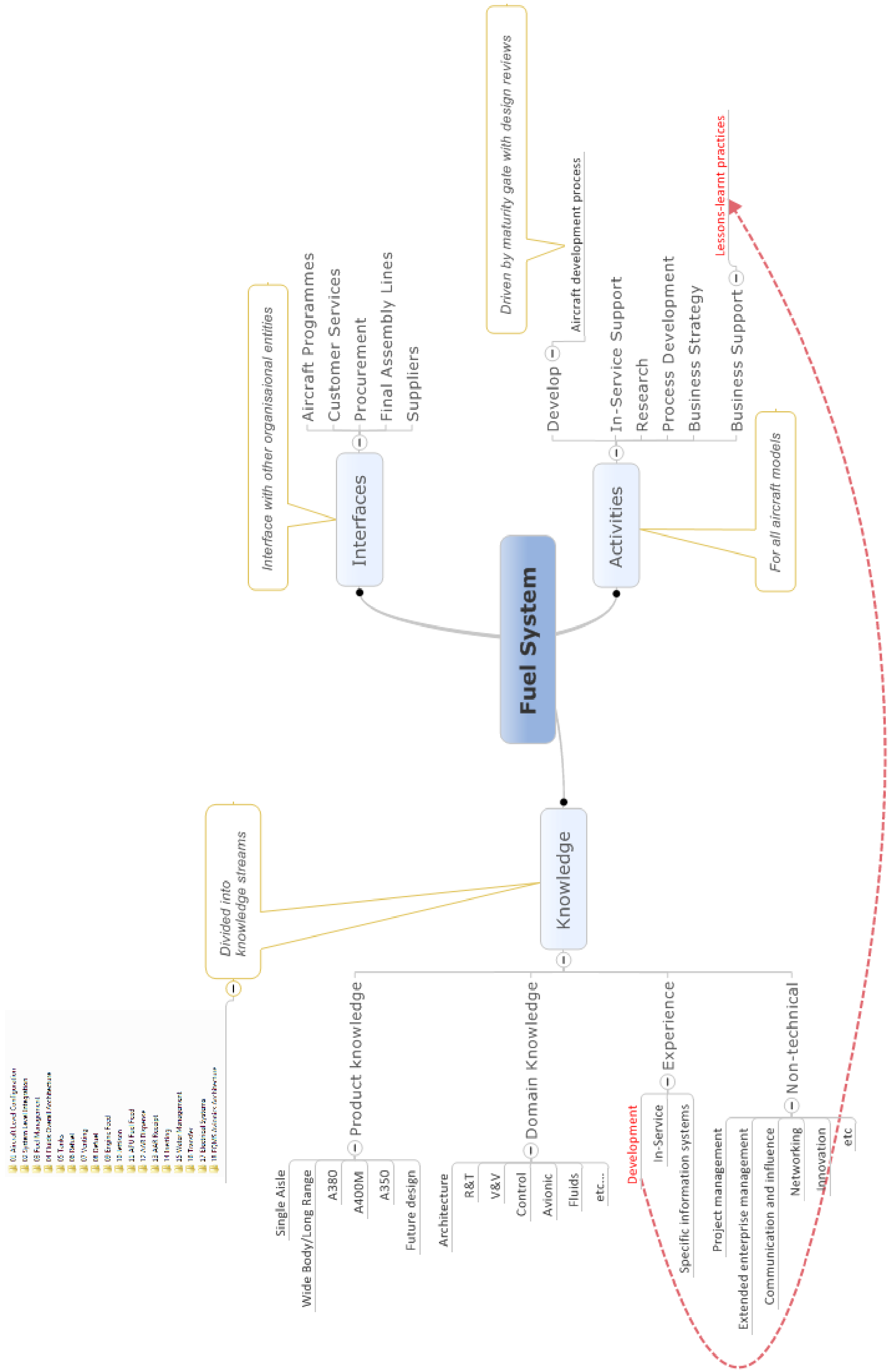

Figure C-1: Mindmap of 1st workshop with Fuel System knowledge management team

C-3.1 Mind map for 2nd workshop with Fuel System Knowledge Management

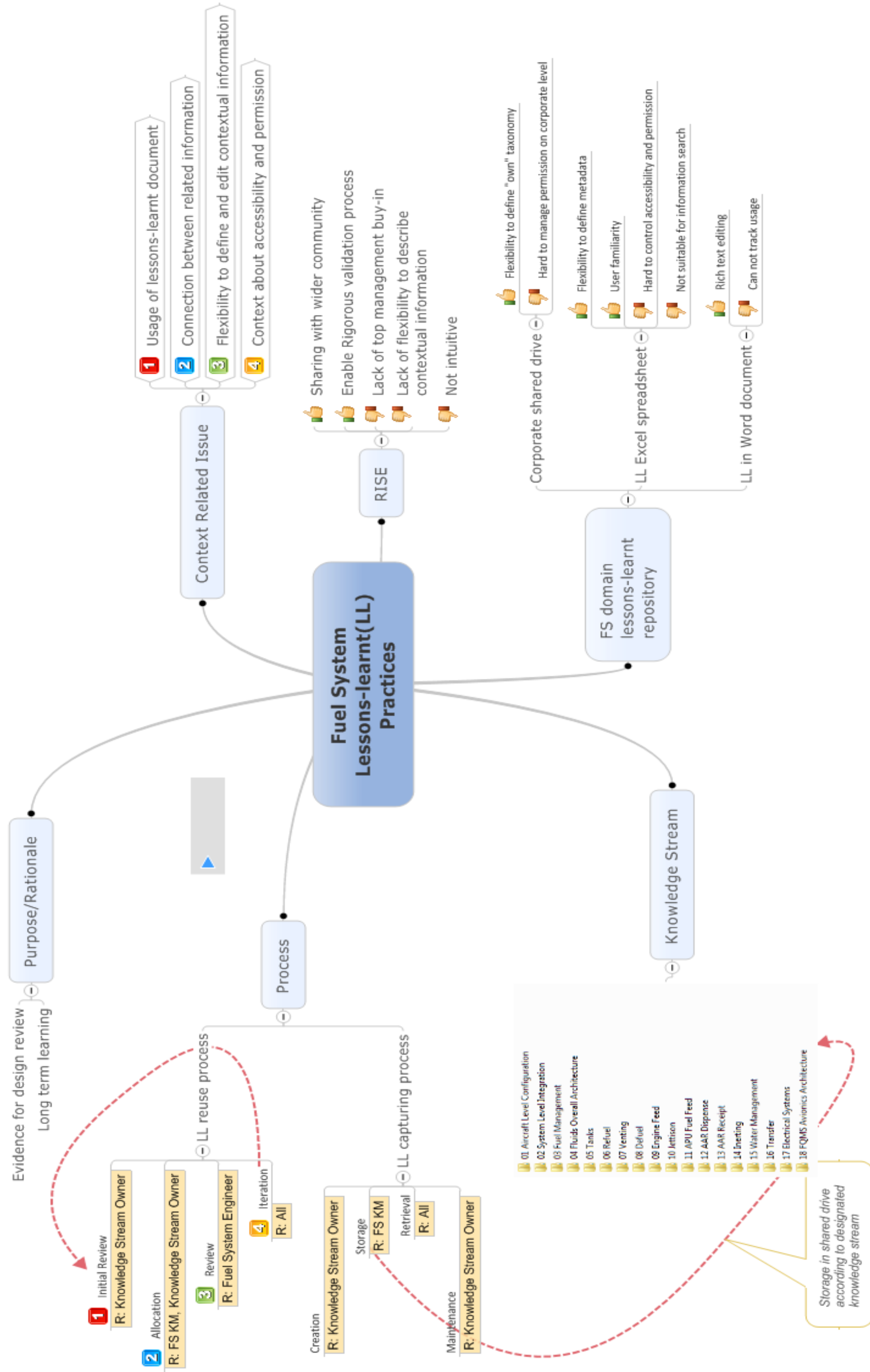

Figure C-2: Mindmap of 2nd workshop with Fuel System knowledge management team